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Final Report

Feasibility Study on the Restoration of Bixler Lake

Submitted To:

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES

LIST OF PHOTOGRAPHS

EXECUTIVE SUMMARY

International Science & Technology, Inc. (IS&T) has provided technical services to the Kendallville Park and Recreation Department in conducting a feasibility study of the restoration of Bixler Lake. The glacially-formed water body, located in Noble County, Indiana, has recently experienced accelerated sedimentation. In 1986, the Indiana Department of Environmental Management (IDEM) placed Bixler Lake in its Class Two category of intermediate quality lakes. The water bodies in this class are known to be adversely impacted by human activities and are moving slowly toward moderate to advanced stages of eutrophication.

The objectives of the feasibility study, funded through the Indiana Lake Enhancement Program (LEP), were four-fold:

- Assess the current condition of the lake system and establish a baseline against which future changes can be measured.
- Identify potential threats to the well-being of the system, both in the lake and in the watershed.
- Recommend lake and/or watershed management practices that minimize such threats.
- Develop a practical, long-term monitoring program to detect and evaluate progress toward improvement.

In pursuit of these goals, IS&T implemented a four-part investigation. First, all relevant background information (e.g., resource maps, soil manuals, fisheries studies) was gathered and reviewed to understand the physical setting. Second, a lake survey was conducted to collect data on water quality, sediment quality, phytoplankton (i.e., algae) abundance, and aquatic macrophyte (i.e., non-algal vegetation) distribution. Third, a watershed survey was completed to identify upland activities resulting in excessive soil erosion and sediment/nutrient transport to the lake. Finally, recommendations were developed to address the identified problem areas. These suggestions included long-term lake and tributary monitoring to evaluate water quality trends and address potential impacts before they impair use of the valuable Bixler Lake resource.

Based on the results of the watershed analysis, lake and tributary sampling, and visual observations, three main tributary sources of sediments and nutrients to Bixler Lake were identified. The streams responsible for the inputs were labeled as follows:

Tributary 1: emptying into the ditch at the northwestern end of the lake

Tributary 3: entering the lake just south of the Bixler Lake Park campground

Tributary 4: entering the lake near its southwestern corner.

The suspected causal agent was different on each of these streams. For Tributary 1, the source of sediment inputs was believed to be a commercial/residential development that had cleared protective vegetation and left the underlying soil susceptible to erosion. For tributary 3, elevated nutrient loads were thought to result from park land runoff and septic system leachate. For tributary 4, no single source of contamination was identified. Because the sub-basin drained by Tributary 4 comprises nearly half of the entire watershed, the cumulative impacts of many upland activities appear to produce high pollutant loads to the lake. It is important to note that a large portion of the nutrient inputs from all sources reached Bixler Lake in sediment-bound form. Controlling sedimentation, therefore, is expected to eliminate much of the nutrient enrichment currently experienced in the water body.

The results of the in-lake and watershed study indicate that Bixler Lake is experiencing moderate sedimentation and eutrophication. The extent of these processes, however, is not severe enough to warrant large-scale restoration measures. The primary thrust of management effort should be directed at controlling sediment and nutrient production off-site. Limiting the input of these pollutants offers the most promising avenue for maintaining the quality of the resource. A general, integrated program for managing Bixler Lake should include: (1) applying appropriate best management practices in the watershed, especially at agricultural and construction sites; (2) reviewing wastewater treatment and runoff management at the Bixler Lake Park facilities; and (3) implementing a sustained program of seasonal water quality monitoring will enable managers to identify and evaluate trends in Bixler Lake and address their implications in a timely and efficient manner.

Simple techniques such as macrophyte harvesting, herbicide application, and chemical nutrient deactivation may be used for improving in-lake conditions on a limited basis as required. Herbicides are probably not needed if the management suggestions outlined in this report are followed. Macrophyte eradication should not be contemplated since the plants play an important role in removing sediments and nutrients entering the lake from tributaries before such contaminants reach open water. Limited weed removal, if navigation is impaired can be accomplished without significantly disturbing the nutrient/sediment filtering capabilities of macrophyte beds. Chemical nutrient deactivation as described by IDEM (1986) should only be used as a last resort and should be targeted at changing nutrient availability to aquatic plants; removing the nutrients from the photic zone; or preventing the release/recycle of nutrients from lake sediments. Chemical nutrient deactivation may be an attractive alternative to herbicide use, however. Finally, the wetlands surrounding the lake and its tributaries should be actively maintained because they play a vital role in removing sediments and nutrients from inflowing water.

SECTION 1. INTRODUCTION

International Science & Technology, Inc. (IS&T) has provided technical services to the Kendallville Park and Recreation Department (Park Department) in conducting a feasibility study on the restoration of Bixler Lake. The work was performed under provisions of the "T by 2000" Lake Enhancement Program (LEP) administered by the State Division of Soil Conservation, Indiana Department of Natural Resources. The LEP was established to ensure the continued viability of Indiana's public-access lakes by (1) controlling sediment and nutrient inflows, and (2) implementing remedial actions to forestall or reverse the impacts of such inflows. Feasibility studies funded through the LEP are intended to document the potential need and scope of future lake enhancement actions.

1.1 BIXLER LAKE

Bixler Lake is located in Noble County Indiana near the northeastern corner of the state (Figure 1-1). The approximate center of the water body lies at 41°26'23" north latitude and 85°14'56" west longitude. The lake has a surface area of 117 acres (47.3 ha), a mean depth of 15.9 feet (4.8 m), and maximum depth of 37.0 feet (11.3 m). Situated adjacent to the town of Kendallville, the lake is surrounded by land owned and maintained by the Park Department. The 3524 acre (1426 ha) watershed is predominantly forest and agricultural land, although recent developments include industrial park expansion and residential construction. Both of these activities are in the northwestern part of the watershed and drain into the lake through a ditch on the northern shore.

A natural, glacially-formed water body, Bixler Lake has been a primary source of recreation for Kendallville since the town was incorporated in 1863. The current Bixler Lake Park (225 acres) was established in the 1960's and is rigorously maintained to provide swimming, boating, camping, and other outdoor entertainment activities. Indeed, the park is the focus of a growing summer tourist industry. In addition to the sports and camping facilities, there are abundant opportunities for wildlife study through the park's Nature Center where public awareness and education are promoted. Attractions include the extensive marshlands to the south and southeast of the lake. Three walking trails have been established there and visitors are guided through wetlands, woodlands, a songbird field, and a waterfowl nesting area. The generally high quality of Bixler Lake and its surroundings may be largely attributed to conscientious management of the resource over the years.

In 1986 the Indiana Department of Environmental Management (IDEM) revised a report that had analyzed the quality of Bixler Lake and assigned an eutrophication index (EI) value of 38, placing it in the Class Two category of intermediate quality, intermediate level eutrophic lakes (IDEM, 1986). Water bodies in this class are characteristically productive with slowly changing trophic conditions and are known to be impacted by human activities. The EI value was based, in part, on a total phosphorus (TP) concentration of 0.09 mg/l and a Secchi disc transparency of 8.0 feet (2.4 m).

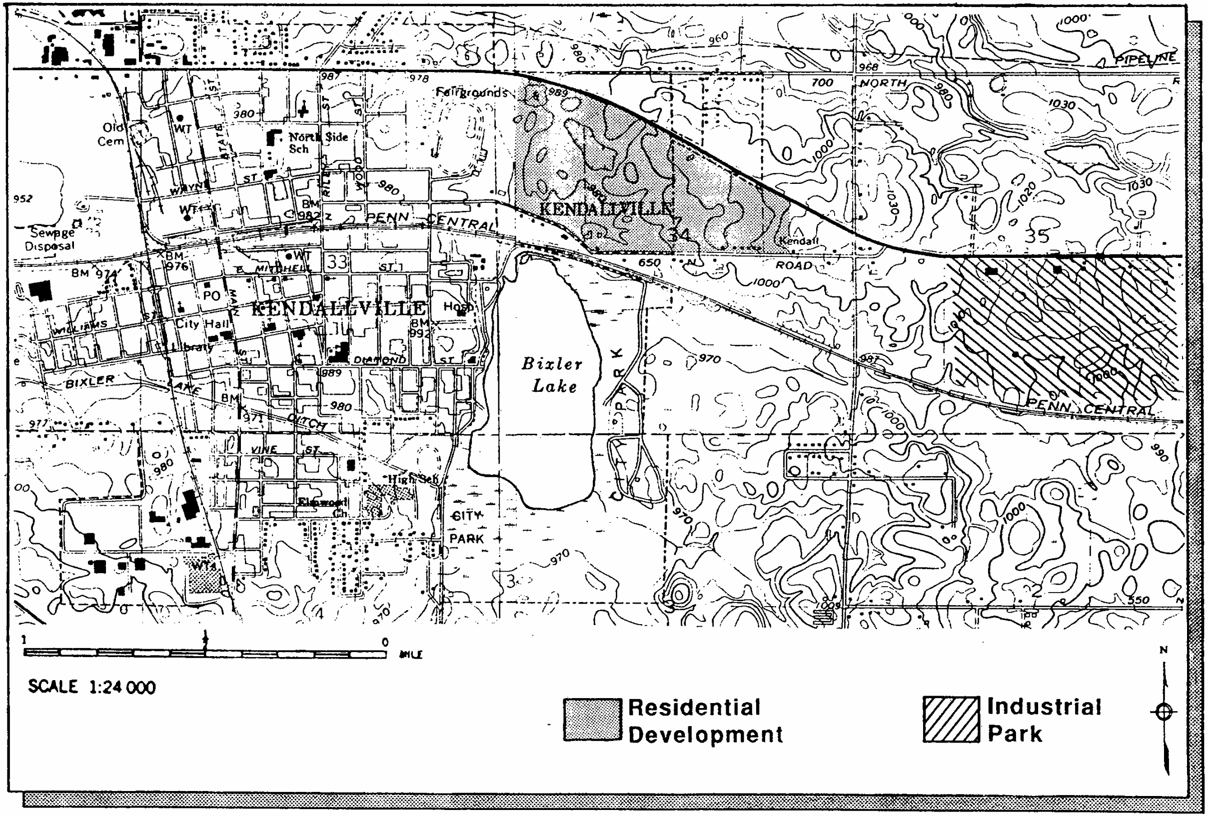

FIGURE 1-1. Portion of U.S. Geological Survey (USGS) Kendallville quadrangle showing the location of Bixler lake and its major features.

1.2 NATURE OF THE PROBLEM

Although IDEM reported that Bixler Lake was in good condition, there has been evidence of accelerated sediment accumulation in recent years. In particular, there has been significant loss of depth in the ditch along the northern shore of the lake and in the lake itself, adjacent to the ditch (Figure 1-2). A shoal has developed in this area and dense stands of rooted aquatic weeds have appeared. Qualitative observations suggest that lake clarity may be decreasing and algal populations increasing.

Prior to the current study, the enhanced sedimentation was thought to be related to development activities in a drainage sub-basin upstream of the ditch. Construction of a residential housing tract in this area was preceded by large-scale clearing of the land with little or no sediment and erosion control. The industrial park located in this sub-basin has also recently expanded. These enterprises reflect growth in the local economy that is expected to continue, potentially creating greater stress on the Bixler Lake system.

1.3 STUDY OBJECTIVES

In conducting the feasibility study on Bixler Lake, IS&T established the following objectives:

- Assess the current condition of the lake system and establish a baseline against which future changes can be measured.
- Identify potential threats to the well-being of the system, both in the lake and in the watershed.
- Recommend lake and/or watershed management practices that minimize such threats.
- Develop a practical, long-term monitoring program to detect and evaluate progress toward improvements.

In pursuit of these objectives, IS&T implemented a four-part program. First, relevant background information (e.g., resource maps, soil manuals, fisheries studies) was gathered and reviewed to understand the physical setting. Second, a lake survey was conducted to collect data on water quality, sediment quality, phytoplankton abundance, and aquatic macrophyte distribution. Third, a watershed survey was completed to identify and locate upland activities resulting in excessive soil erosion and sediment transport to the lake. Finally, a program for implementing mitigative technologies was developed to address the identified problems. Methods and results of this study are presented in the sections that follow.

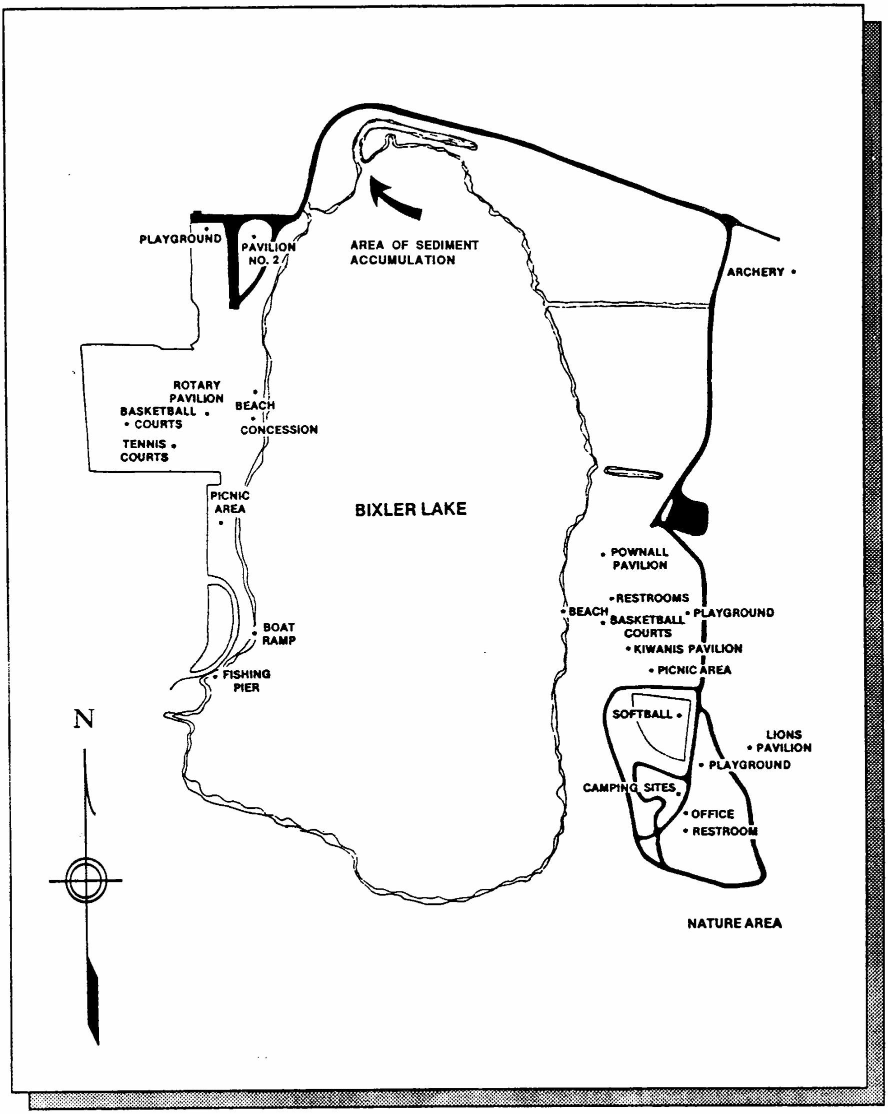

FIGURE 1-2. Detailed picture of Bixler Lake showing the ditch and area of sediment accumulation.

SECTION 2. METHODS

This section of the report provides background on the methods used to complete the Bixler Lake feasibility study. Data collection involved three sub-tasks: (1) a literature survey; (2) a lake survey; and (3) a watershed survey. These sub-tasks are described below.

2.1 LITERATURE SURVEY

A literature survey was performed to identify and obtain all historical water quality, hydrologic, and land use data relevant to Bixler Lake. Contacted agencies included:

- Kendallville Park and Recreation Department
- Kendallville City Engineer's Office
- Noble County Health Department
- Noble County Surveyor's Office
- Indiana Department of Environmental Management
- Indiana Department of Natural Resources
- U.S. Soil Conservation Service (Noble County)

Water quality data were requested from the Park Department, the Noble County Health Department, and the Indiana Department of Environmental Management. Although all types of water quality information were sought, parameters of specific interest included: nutrients, Secchi disk transparency, chlorophyll-a, total solids, fecal coliform, and dissolved oxygen. Biological data (e.g., species composition, abundance) were also sought.

Climatic, hydrologic, and physiographic information was obtained through the Noble County Surveyor's Office, the Kendallville City Engineer's Office, the U.S. Soil Conservation Service (SCS), the U.S. Agricultural Stabilization and Conservation Service (ASCS), the U.S. Geological Survey (USGS), and the National Oceanic and Atmospheric Administration (NOAA). Data sources included:

- Aerial photographs
- Topographic maps
- Soil surveys and erodible soil maps
- Agricultural practice reports
- Lake bathymetric maps
- Wetland reports
- Precipitation chemistry reports

Because USGS land use maps were not available for Noble County, aerial photographs, topographic maps, and ground surveys were combined to delineate land use coverage in the watershed (Section 2.3.4).

A thorough search was also conducted in the Kendallville and Noble County Public Libraries. Information on important indigenous species and human populations was identified and obtained. News clippings and other reports were collected and reviewed to provide historical perspective on activities at Bixler Lake.

2.2 LAKE SURVEY

In order to obtain information required for a detailed assessment of the current conditions in Bixler Lake, a field survey of the water body was conducted between 12-14 July 1989. The locations of sample sites are presented in Figure 2-1. Components of the survey included:

- In-situ water quality measurements
- Chemical water quality measurements
- Biological water quality measurements
- Lake sediment core analyses
- Aquatic macrophyte mapping
- Bathymetric mapping

2.2.1 In-situ Measurements

In-situ water quality parameters were sampled in the deepest area of the lake, at station WQ-1. Measurements of pH, dissolved oxygen (DO), temperature, and conductivity were made at 4 foot (1.2 m) intervals from the lake surface to the sediment surface using a Hydrolab Surveyor II (Hydrolab Corporation, Austin, TX). Light transmission at a depth of 3 feet (0.9 m) was recorded using a Martek Model XMS (Martek Corporation, Irvine, CA) transmissometer. The transmissometer was calibrated while out of the water in sunlight (i.e., 100% transmission). Secchi disk transparency was also measured. Results were used to characterize mid-summer conditions in the lake and to construct an index of trophic status.

2.2.2 Chemical Measurements

Water samples were collected with a 6.6 quart (6.2 l) Van Dorn sampler (Wildco Supply Company, Saginaw, MI) at Station WQ-1. Samples were taken at three depths: (1) just below the lake surface; (2) near the thermocline, at 18 feet (5.5 m); and (3) one foot above the lake bottom, at 37 feet (11.3 m). Samples were marked and placed in acid-washed, one-liter Cubitainer containers (Hedwin Corporation, Baltimore, MD). Separate fecal coliform aliquots from each depth were placed in six-ounce Whirl-Pak bags (Nasco, Inc., Fort Atkinson, WI). All samples were stored on ice in the dark and subsequently shipped to the IS&T analytical laboratory via overnight air freight. The samples were received and the analyses were begun within 24 hours of collection. Parameters and methods used in the chemical determinations are listed in Table 2-1. Results were used to characterize mid-summer conditions in the lake and to construct an index of trophic status.

Water samples were collected from four tributaries of the lake during a storm event at stations STR-1, STR-2, STR-3, STR-4. One grab sample was taken from each tributary by Mr. James Goodwin (Kendallville Park and & Recreation Department) in 1-liter sample bottles. Samples were immediately chilled and shipped to the IS&T analytical laboratory. Through the analysis of these water samples, tributary contributions of sediments and nutrients to the lake were estimated.

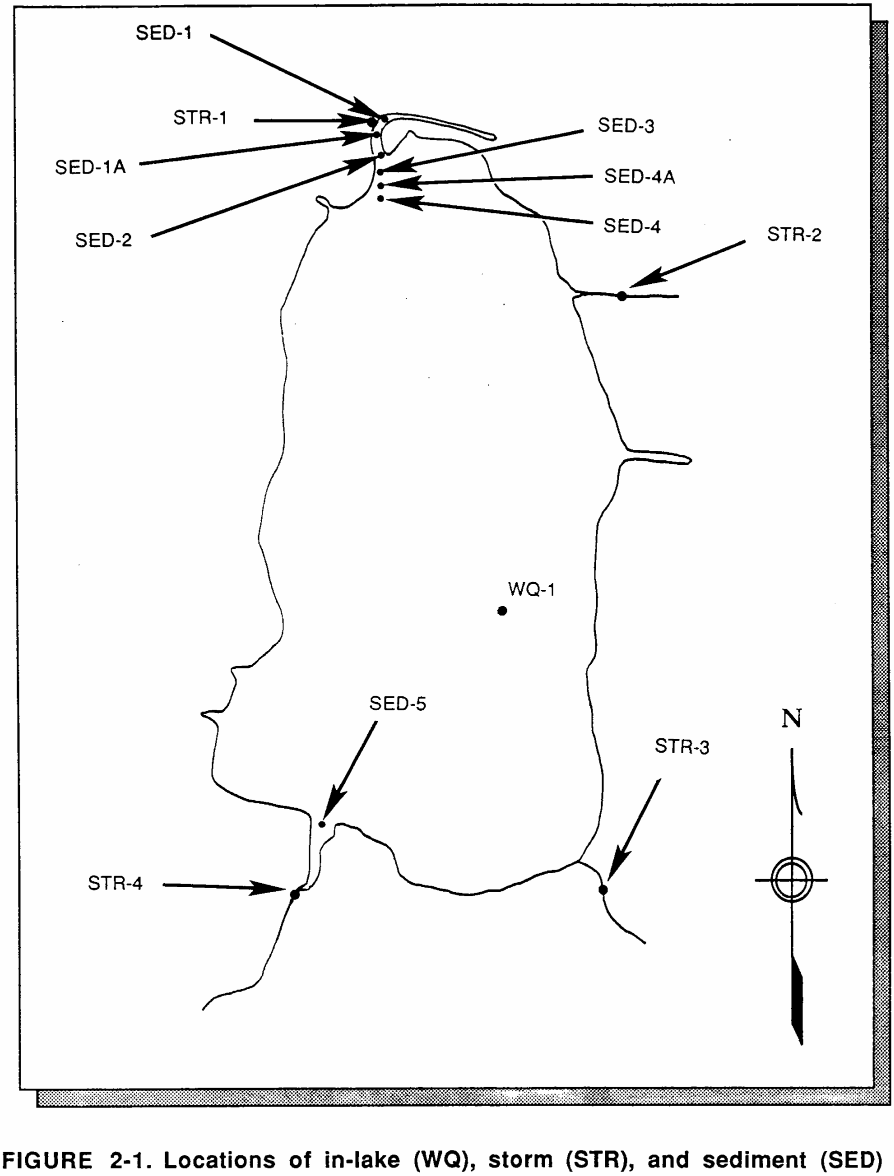

FIGURE 2-1. Locations of in-lake (WQ), storm (STR), and sediment (SED) sampling stations on Bixler Lake.

TABLE 2-1. Parameters and analytical methods used in evaluating Bixler Lake water samples.

PARAMETER	METHOD	REFERENCE
Total phosphorus (TP)	Flow Injection Analysis	EPA, 1983
Soluble phosphorus (SP)	Flow Injection Analysis	EPA, 1983
Nitrate (NO3)	Flow Injection Analysis	EPA, 1983
Nitrite (NO2)	Flow Injection Analysis	EPA, 1983
Ammonia (N-NH4)	Flow Injection Analysis	EPA, 1983
Chlorophyll a (Chl-A)	Spectrophotometer	APHA, 1985
Total Suspended Solids (TSS)	Gravimetric	EPA, 1983
Fecal Coliform (FC)	Incubation, Visual Count	APHA, 1985

NOTE: EPA = U.S. Environmental Protection Agency
APHA = American Public Health Association

2.2.3 Biological Measurements

Phytoplankton samples were collected at station WQ-1 using a 0.5 meter, 63.0 μ mesh net. Vertical tows were made from depths of 5 feet (1.5 m) and 15 feet (4.6 m). The latter depth was chosen so samples would include water from just below the thermocline. Samples were preserved in a 4% formalin solution, stored in 1-liter containers, and shipped to the laboratory. Results were used to calculate a trophic index. Phytoplankton identifications were made using the Etermohl method (Wetzel and Likens, 1958).

2.2.4 Sediment Core Analyses

Sediment samples were taken to determine the nature and extent of sedimentation in Bixler Lake. Cores were collected at in-lake stations SED-1, SED-2, SED-3, SED-4, and SED-5 (Figure 2-1) using a Wildco piston corer (Wildco Supply Company, Saginaw, MI). Each core was photographed and divided into visibly distinct layers. The depth and content of each layer was noted and described in the field. The uppermost layer of each core was analyzed in the laboratory for total phosphorus (TP), total Kjeldahl nitrogen (TKN), and volatile solids (VS). An Extraction Procedure (EP) toxicity test was performed on all core samples. Analytical methods are listed in Table 2-2.

Measurements of unconsolidated sediment thickness were taken along transects at five stations (SED-1, SED-1A, SED-2, SED-3, SED-4A) as shown in Figure 2-1. At each station, a sediment probe was used to detect depth to sediments and probe rejection depth (i.e., maximum depth to which a probe will penetrate). Unconsolidated sediment thickness was calculated as the difference between rejection depth and depth to sediment.

TABLE 2-2. Analytical methods used to evaluate Bixler Lake sediment samples.

PARAMETER	INSTRUMENT OR METHOD	REFERENCE
E.P. Toxicity Test	Extraction Procedure	EPA, 1986
Total Phosphorus	Flow Injection Analysis	EPA, 1983
Total Nitrogen	Flow Injection Analysis	EPA,1983
Volatile Solid Total	Gravimetric	USGS, 1979

NOTE: EPA = U.S. Environmental Protection Agency
USGS = U.S. Geological Survey

2.2.5 Aquatic Macrophyte Mapping

Hydrophytic vegetation was surveyed to quantify and map the distribution of floating, emergent, and submergent plant species. The perimeter of the lake was canvassed on foot and by boat. Plant specimens were photographed, identified, and collected in the field. Areal coverages were sketched and digitized to create plant distribution maps.

2.2.6 Bathymetric Mapping

A bathymetric survey of Bixler Lake was conducted using an Eagle Mach 1 recording fathometer (Eagle Electronics, Catoosa, OK) operated from a Jon boat. Landmarks (e.g., buildings) located along the lake shore were used to establish a survey grid of defined transects (Figure 2-2). Each transect was traversed at a constant speed, and fathometer recordings were annotated at the beginning and end of each run. Fathometer traces were subsequently digitized. Bathymetric maps were produced using "Surfer," a contour mapping software package (Golden Software, Inc., Golden, CO). Maximum depth, mean depth, and lake volume were calculated from area/volume ratio analyses of the bathymetric maps. Results were compared with previous bathymetric data to assess sedimentation rates.

2.3 WATERSHED SURVEY

A comprehensive effort was undertaken to describe conditions in the watershed. Special attention was directed to existing activities that could result in excessive sediment or nutrient loading (e.g., land clearing, construction, intensive tilling). Components of the watershed survey included:

- Climatic evaluation
- Hydrologic characterization
- Soil type delineation
- Land use delineation
- Sediment/nutrient modeling

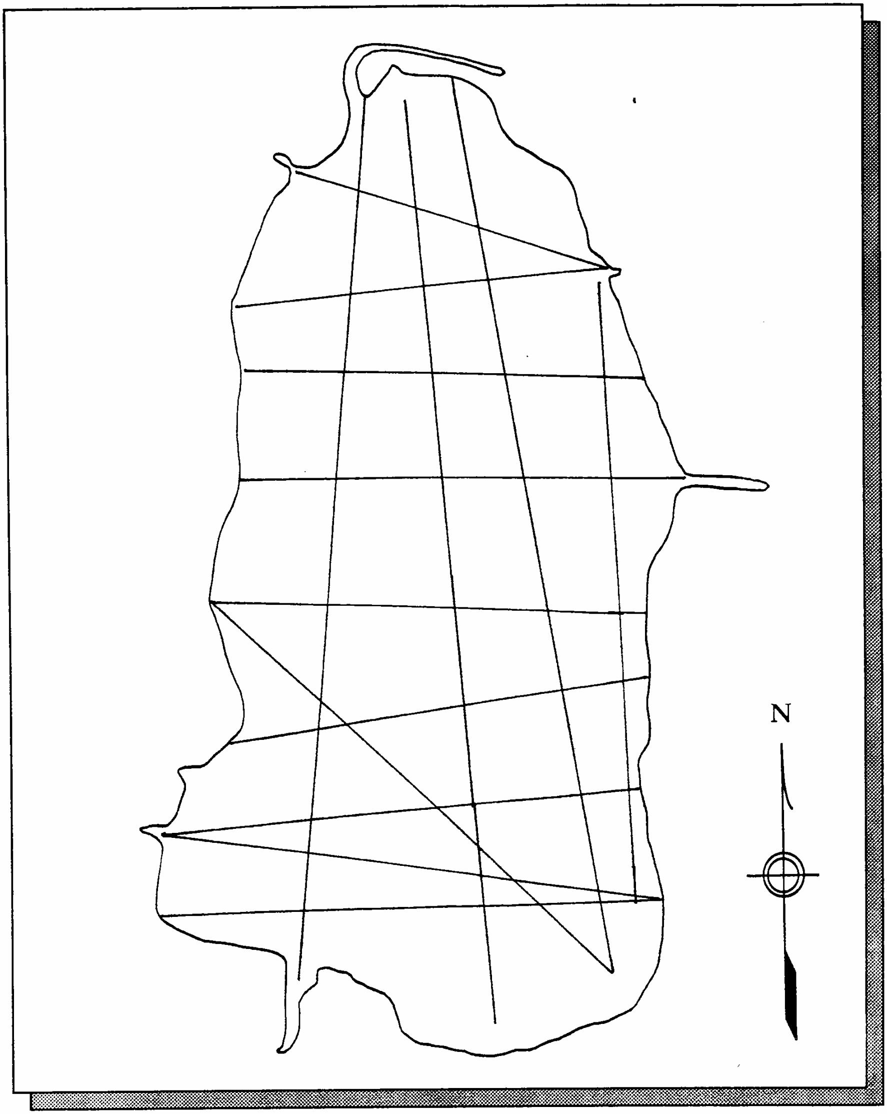

FIGURE 2-2. Survey grid used during bathymetric mapping of Bixler Lake.

2.3.1 Climatic Evaluation

Two types of atmospheric information were obtained and analyzed during the study: (1) general climatic data (e.g., temperature, rainfall, solar radiation); and (2) precipitation chemistry data. General climatic conditions in the Bixler Lake watershed were described from reports compiled by the U.S. Department of Commerce (DOC, 1968) and by the Soil Conservation Service (USDA, 1977). In addition, a weather simulation program (Nick and Lane, 1989) was used to construct 30-year, monthly averages for maximum temperature, minimum temperature, total precipitation, storm duration, and solar radiation. Historical atmospheric information for the Fort Wayne area was obtained from the National Climatic Data Center and used to represent conditions in Noble County. Detailed descriptions of the parameters, statistics, and routines incorporated in the weather model are presented in the above-noted reference.

Specific information on precipitation chemistry was unavailable for Bixler Lake; therefore, interpolated averages from data collected at the closest Great Lakes monitoring stations (i.e., Benton Harbor, Michigan and Put-in Bay, Ohio) were used to estimate total phosphorus and total nitrogen inputs from annual rainfall. No data, however, were available to estimate dry loading.

2.3.2 Hydrologic Characterization

Hydrological characterization of the watershed centered around two types of analyses: (1) a general description of watershed and lake morphological attributes, including evaluation of physical indices relating watershed size and shape to runoff behavior; and (2) calculation of an approximate mass-balance water budget. The watershed boundary was outlined on 7.5 Minute Series USGS topographic maps. A computerized opisometer (i.e., map distance/area measuring device) was used in conjunction with mechanical means to determine the nature of watershed features including total area and perimeter, axial length, average width, average slope, maximum and minimum slope, center of gravity, drainage pattern, drainage density, shape factor, compactness coefficient, eccentricity, and orientation. Lake surface area and perimeter were also measured. A description of the significance of each of these factors is presented below.

Area: The extent of the ground surface inside the catchment; area is a fundamental unit of interest in all watershed studies.

Perimeter: The length of the boundary around the catchment; perimeter is helpful in determining watershed shape characteristics.

Axial Length: The distance between the watershed outlet (i.e., lake overflow) and the farthest point on the catchment boundary; axial length is helpful in determining the time required for rain water falling on the most remote section of the catchment to reach the overflow (i.e., maximum time necessary for trans-watershed flow).

Average Width: Literally, the ratio of catchment area to axial length; average width is a shape descriptor.

Average slope:	A measure of elevation change per unit of horizontal distance within the catchment; average slope describes the general "steepness" of the watershed. "Steepness" partly determines the velocity (i.e., erosional capacity) of runoff.
Minimum slope:	A third measure of elevation change per unit of horizontal distance within the catchment; minimum slope describes the lowest degree of "steepness" in the watershed. This parameter is often used with its counterpart, maximum slope, to indicate the range of "steepness."
Maximum slope:	Another measure of elevation change per unit of horizontal distance within the catchment; maximum slope describes the highest degree of "steepness" in the watershed. This parameter is often used with its counterpart, minimum slope, to indicate the range of "steepness."
Center of Gravity:	The areal centroid of the catchment; this measure pinpoints the exact center of the watershed.
Drainage Pattern:	The arrangement of natural channels within a catchment; drainage pattern not only describes the layout of the streams but also indicates the types of existing soils/bedrock (i.e., drainage configurations are dependent on the erosional resistance of the existing substrate).
Drainage Density:	The ratio of catchment stream length to catchment area; drainage density measures the efficiency of drainage afforded by defined channels (i.e., extensive stream networks lead to efficient drainage).
Form Factor:	The ratio of watershed average width to axial length; the form factor indicates the relative shape of the watershed.
Compactness Coefficient:	The ratio of the perimeter of the watershed to the perimeter of a circle with an equal area; the compactness coefficient indicates the nature and timing of runoff contributions to stream flow (i.e., circular watersheds are regular in shape and tend to have all areas contributing runoff equally within a distinct time span; non-circular watersheds tend to have nonuniform and less predictable runoff characteristics).
Eccentricity:	A measure relating watershed shape to an ellipse; this parameter also indicates the nature and timing of runoff contribution to stream flows.
Orientation:	Synonymous with "aspect"; orientation indicates the compass direction toward which most slopes in the watershed face.

An annual water budget was developed for Bixler Lake based on estimates of water mass inputs and outputs (Table 2-3). Parameters considered as inputs included direct rainfall, runoff, and spring inflow. Parameters considered as outputs included lake outlet overflow, evaporation, and basin leakage. Annual rainfall volumes applied to the water budget were derived from 30-year averages produced by the computerized weather generator (Section 2.3.1). Runoff volumes were calculated using the Curve Number Method described in U.S. Soil Conservation Service Technical Release 55 (USDA, 1986). Lake evaporation was interpolated from pan evaporation figures supplied in the Weather Atlas of the United States (DOC, 1968). Because data for springs and leakage in the lake were unavailable, these factors were assumed to be negligible. Lake overflow was calculated as the residual of inflow minus evaporation. No other water inflows or outflows were identified.

TABLE 2-3. Mass-balance relationship and input/output parameters considered in the Bixler Lake water budget.

MASS-BALANCE RELATIONSHIP:	Inputs = Outputs
INPUTS:	OUTPUTS:
Rainfall (monthly/annual)	Lake Overflow (monthly/annual)
Stream flow/Runoff (monthly/annual)	Evaporation (monthly/annual)
Under-basin Springs[1]	Under-basin Leakage[1]

[1] Assumed to be 0 because no data were available for these parameters.

In addition to water budget parameters, estimates were made for potential evapotranspiration and hydraulic retention time. Potential evapotranspiration (PET) is a measure of maximum possible evaporation through the soil and vascular plants, given an unlimited water supply. Estimates of PET were generated using the Thornthwaite Method (Thornthwaite and Mather, 1956), an empirical technique based on mean monthly temperatures. This technique was chosen over other methods because the information requirements were readily met by the existing climatic data.

Hydraulic retention time is a measure of the time required for the volume of lake inflow water to equal the volume of the lake itself. It can be thought of as the period of time necessary to completely replace the volume of the lake. For this study, hydraulic retention time was computed as the ratio of lake water volume to the annual inflow water volume. Results were expressed in terms of years.

2.3.3 Soil Type Delineation

Erodible and non-erodible soils in the Bixler Lake watershed were identified using SCS soil manuals and erosion study documents for Noble County (NCSWCD, 1987; USDA, 1977). Areal coverages of these soils were extracted from existing maps and then digitized. Erodible soil maps were produced for this report using IS&T proprietary software. Results were used as input parameters for modeling sediment/nutrient dynamics (Section 2.3.5).

2.3.4 Land Use Delineation

Land use coverages in the Bixler Lake watershed were identified and delineated using a combination of (1) USGS 7.5 minute series topographic maps; (2) aerial photographs (1 to 2000 scale); and (3) site reconnaissance. The watershed boundary was outlined on topographic maps and digitized along with key geographical features (e.g., lake shorelines, streams, roads, towns). Using aerial photographs, land uses were delineated and assigned to one of sixteen possible categories (Table 2-4). The land uses were then

TABLE 2-4. Land use categories designated in the watershed survey.

1)	Water Surface
2)	Wetlands (including approx. stream corridors)
3)	Forest (tree groups larger than 1/4 acre)
4)	Open Land/Vacant Lots (no structures or livestock)
5)	Pasture (grazed lands)
6)	Row Crops (corn, beans, etc.)
7)	Non-row Crops (grains)
8)	Orchard
9)	Feedlot
10)	Low Density Residential (1 dwellings/acre)
11)	Medium Density Residential (2-4 dwellings/acre)
12)	High Density Residential (5 or more dwellings/acre)
13)	Commercial/Industrial (industrial parks, malls)
14)	Institutional (schools, parks, golf courses)
15)	Bare Ground (construction sites)
16)	Resource Extraction (borrow pits, timber sites)

digitized and overlain onto the watershed boundary and geographical feature files. Coverage maps and tabular summaries of land use in the whole watershed and in sub-basins were produced for this report with IS&T proprietary software. Results were used as input parameters for modeling sediment/nutrient dynamics (Section 2.3.5). All maps were verified during ground reconnaissance visits.

2.3.5 Sediment/Nutrient Modeling

Information on land use, climate, soils, and hydrology were combined to provide input parameters for use in the Agricultural Nonpoint Source Pollution Model (AGNPS), a system developed by the Agricultural Research Service (ARS) in cooperation with the Minnesota Pollution Control Agency and the Soil Conservation Service. The microcomputer-based model was designed to evaluate the sediment, nutrient, and hydrologic quality of runoff from land in agricultural regions. AGNPS operates on a grid basis and requires the watershed to be divided into a series of uniform square areas called "cells." Twenty-two physical and chemical characteristics must be defined and input for each cell before the model is run (Table 2-5). Potential pollutants are routed through the watershed starting at cells along the basin divide and are moved toward the outlet in a stepwise manner. Depending on the defined parameters, each cell exerts an influence on the runoff, either increasing or diminishing the nonpoint pollutant load. Sediment, nutrient, and hydrologic characteristics may be summarized for any cell along the flow path and at the watershed outlet. The model provides estimates for single precipitation events only, and, therefore, requires the user to define a "design storm" for the analysis.

TABLE 2-5. Input parameters used in the AGNPS model[1].

TITLE	DESCRIPTION
Cell Number	ID number of current cell
Receiving Cell	ID number of cell receiving outflow from current cell
SCS Curve Number	Relates runoff mass to rainfall mass (inches)
Field Slope	Mean slope of fields (%)
Slope Shape	Shape of slopes (i.e., concave, convex, or uniform)
Slope Length	Mean slope length of fields (feet)
Channel Slope	Mean slope of stream channel (%)
Side Slope	Mean slope of stream channel banks (%)
Roughness	Manning's "roughness" coefficient for channels
Soil Erodibility	K-Factor from Universal Soil Loss Equation
Crop Practice	C-Factor from Universal Soil Loss Equation
Conservation Practice	P-Factor from Universal Soil Loss Equation
Surface Condition	Indicates degree of land surface disruption
Aspect	Principal drainage direction
Soil Texture	Gross texture of the soil (i.e., sand, silt, clay, or peat)
Fertilization	Level of added fertilizer
Incorporation	Percentage of fertilizer left on soil after the storm
Point Source Flag	Indicates presence/magnitude of point source (e.g., treatment plant)
Gully Source	Estimate of the magnitude of gully erosion
COD	Level of chemical oxygen demand generated
Impoundment Flag	Indicates presence/number of terrace systems
Channel Flag	Indicates presence/number of defined streams

[1] Parameters represent estimated conditions within each cell.

Based on the recommendations of AGNPS developers, the Bixler Lake watershed was divided into a series of 45-acre cells. Each cell was then summarized according to the parameters listed in Table 2-5. The design storm chosen for this exercise was the 2-year, 24-hour event (i.e., the largest storm lasting 24 hours that can be expected to occur once every 2 years). This storm was chosen because: (1) suitable climatic input data were available; (2) the storm was large enough to produce meaningful model output; and (3) the storm was small enough to be considered fairly common. Due to the recent industrial park expansion and residential construction activities in the watershed and because of observed runoff conditions, pre-development and post-development modeling scenarios were evaluated. Nutrient, sediment, and runoff maps highlighting potential watershed "trouble spots" were produced using the AGNPS Graphical Interface System.

SECTION 3. SURVEY RESULTS AND DISCUSSION

Results of the literature, lake, and watershed surveys are presented in this section of the report. Most of the discussion centers on the findings of the lake and watershed surveys, with references to the literature search assuming a supporting role. Identification of sediment and nutrient sources within the watershed is provided following presentation of the survey results and serves to summarize the study findings in practical, management-oriented terms.

3.1 LAKE SURVEY RESULTS

The findings of the Bixler Lake field survey are presented in the following paragraphs. Components of the investigation included in-situ, chemical, and biological water quality measurements; lake sediment core analyses; aquatic macrophyte mapping; and bathymetric mapping. Using data from these components, summertime conditions in the lake were summarized and an eutrophic index was calculated.

3.1.1 In-situ Water Quality

In-situ water quality measurements (i.e., temperature, pH, DO, and conductivity) gathered during the study are listed by depth in Table 3-1 and presented graphically in Figures 3-1a through 3-1d. These data indicate that Bixler Lake was thermally stratified

TABLE 3-1. Results of in-situ water quality sampling conducted at Bixler Lake on 13 July 1989.

Depth (feet)	Depth (m)	Temperature (°F)	Temperature (°C)	pH	DO (mg/l)	Conductivity (mmho/cm²)
0.0	0.0	78.8	26.0	8.40	9.37	0.426
4.0	1.2	78.6	25.9	8.36	9.02	0.429
8.0	2.4	78.4	25.8	8.23	7.85	0.430
12.0	3.7	67.1	19.5	7.49	2.02	0.480
16.0	4.9	58.8	14.9	7.47	0.09	0.492
20.0	6.1	57.0	13.9	7.52	0.13	0.497
24.0	7.3	55.2	12.9	7.50	0.07	0.499
28.0	8.5	53.1	11.7	7.49	0.07	0.502
32.0	9.8	52.5	11.4	7.47	0.07	0.501
36.0	11.0	52.2	11.2	7.45	0.08	0.501
37.0	11.3	52.0	11.1	7.45	0.08	0.502

Secchi Disk Transparency: 6.0 feet (1.8 m)

Light Transmission at 3 feet (0.91 m): 56.7 %

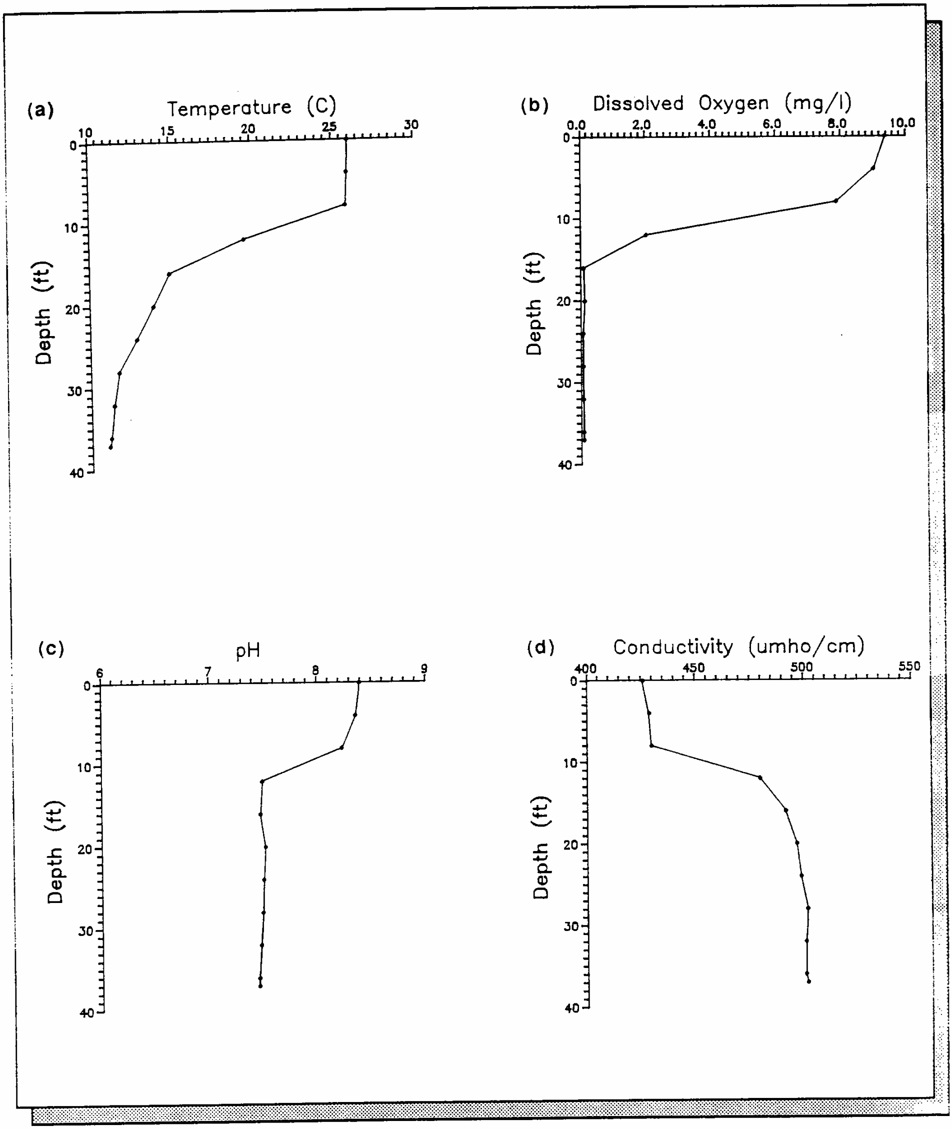

FIGURE 3-1. Graphical representations of in-situ water quality data taken at Bixler Lake on 13 July 1989.

when the samples were collected. The lake thermocline was located between 8 and 12 feet (2.4 and 3.7 m), as indicated by the maximum rate of decrease in temperature at those depths (Figure 3-1a). The dissolved oxygen concentration also decreased rapidly within this zone. The clinograde DO profile of Bixler Lake, (Figure 3-1b) typified by the anaerobic hypolimnion, is characteristic of eutrophic lakes. Measurements of pH ranged between 8.4 (surface) and 7.5 (bottom) and are displayed in Figure 3-1c. The majority of open lakes have a pH range between 6 and 9 units. Such lakes are regulated by the carbonate buffering system. The distribution of pH is influenced by photosynthetic utilization of carbon dioxide (CO_2) in the trophogenic zone and respiratory generation of CO_2 throughout the water column and sediments. As the accumulation of CO_2 exceeds oxygen production and the hypolimnion becomes anaerobic, the pH will decrease markedly. An inverse clinograde curve was observed for conductivity measurements (Figure 3-1d). It is common in anoxic waters for the specific conductance to increase in the hypolimnion. Water clarity was average, with a Secchi disk depth of six feet. This depth was within the 50th percentile of 40 lakes previously studied in Indiana (IDEM, 1986). Light transmission was 56.7% at a depth of 3 feet (0.91 m).

3.1.2 Chemical Water Quality

Chemical water quality measurements of the in-lake samples taken at station WQ-1 are listed in Table 3-2. The values obtained for Chlorophyll a (Chl a) are within the range

TABLE 3-2. Results of water chemistry sampling conducted at Bixler Lake on 13 July 1989.

Depth (feet)	Depth (m)	Chl a (mg/m_3)	Fecal (#/100 ml)	$N\text{-}NH_4$ (mg/l)	NO_2 (mg/l)	NO_2+NO_3 (mg/l)	SP (mg/l)	TKN (mg/l)	TP (mg/l)
0.0	0.0	10.7	3.0	0.100	0.000	0.064	0.012	0.131	0.024
19.0	5.8	24.1	0.0	0.080	0.000	0.067	0.014	0.299	0.037
37.0	11.3	1.9	3.0	0.920	0.000	0.066	0.167	1.383	0.206
Averages		12.2	2.0	0.367	0.000	0.066	0.064	0.604	0.089

of those found in both mesotrophic and eutrophic lakes (Wetzel, 1983). It was interesting to note that the Chl a concentration at 19 feet (5.8 m) was 24.1 mg/m^3, while DO was nearly nonexistent. This finding was at first thought to be anomalous since blue-green algae do not normally exist under such low DO conditions. Blue-greens can, however, exhibit dynamic growth patterns with blooms appearing and disappearing rapidly, and cells are often not homogeneously distributed throughout the water column. Dead algae settling to the bottom from a previous bloom could have been collected at 19 feet and chlorophyll extractions made from them. This explanation would account for the inconsistent measurement. None of the other parameters displayed such discrepancies. The fecal coliform counts were very low or nonexistent in all three samples. The high value of ammonia ($N\text{-}NH_4$) at 37 feet (11.3 m) was attributed to the anaerobic conditions at that depth; ammonia concentrations are typically high in poorly oxygenated waters. The nitrite-nitrate (NO_2+NO_3) concentrations were consistent throughout the lake and were much less than average concentrations found in similar moderately eutrophic lakes in temperate regions (Wetzel, 1983). The absence of detectable nitrite (NO_2) in the lake was to be expected. Nitrite is readily converted by the bacteria *Nitrobacter* to nitrate (NO_3) and rarely accumulates unless organic pollution is high. Relatively high concentrations of total Kjeldahl nitrogen (TKN) were observed near the sediment-water interface. TKN represents organically-bound nitrogen. High concentrations are representative of large amounts of organic matter present in the hypolimnetic waters. Total phosphorus (TP) concentrations were typical of mesotrophic or eutrophic waters. Increased total and soluble phosphorus content near the bottom is common in eutrophic lakes with strongly clinograde oxygen profiles (Wetzel, 1983). Much of the increase was probably due to soluble phosphorus (SP) near the sediment-water interface, as 81 percent of the TP near the lake bottom was from SP (Table 3-2). The ratios of total nitrogen (TN) TN to TP (N:P) at all depths sampled were less than 10:1. N:P ratios less than 13:1 are characteristic of lakes where nitrogen is the limiting nutrient. Typically, in nitrogen-limited lakes, external sources provide more phosphorus than can be fully utilized by photosynthesis.

Results of storm event sampling are presented in Table 3-3. With the exception of NO_3, the highest nutrient concentrations were observed at site STR-3, located on a stream that drains the southern end of Bixler Lake Park. This finding was believed to reflect the combined impacts of park grounds-keeping practices (e.g., fertilizer application) and the proximity of campground sanitary (i.e., septic) facilities. Better quantification of fertilizer application rates and septic system usage is needed before definitive statements may be made regarding this assumption, however. The second highest concentration of total suspended solids (TSS) was also found at STR-3, a result that may implicate park activities as well. It should be noted, however, that the STR-3 stream collects runoff from the steepest, and arguably most erosion prone areas of the entire watershed, a fact that may account for enhanced solids loading.

TABLE 3-3. Results of storm event sampling in Bixler Lake tributaries.

STATION	$N\text{-}NH_4$ (mg/l)	TKN (mg/l)	NO_3 (mg/l)	SP (mg/l)	TP (mg/l)	TSS (mg/l)
STR-1	0.118	1.214	0.347	0.006	0.122	13.80
STR-2	0.024	1.586	0.000	0.022	0.067	0.80
STR-3	0.351	1.781	0.850	0.121	0.389	32.00
STR-4	0.086	1.097	1.043	0.110	0.115	70.90

Site STR-4 was observed to have the highest TSS and NO_3 concentrations during the sampled storm. Concentrations of the other parameters were also relatively high. Two explanations were postulated for this finding: (1) the STR-4 stream drains the largest sub-basin in the watershed and, therefore, has the potential to experience the greatest volumes of both water and sediment/nutrient loading; and (2) the waterway flows through straightened channels adjacent to a residential area, including a trailer park, immediately south of Kendallville. Elevated solids concentrations are characteristic of residential runoff. Again, more intensive monitoring is required before causal relationships can be reliably established.

Moderately high concentrations of TKN and TSS were found at site STR-1, in the stream draining the development area just north of Bixler Lake. It should be noted that this stream drains the smallest sub-basin in the watershed, yet experiences sediment and nutrient loads comparable to those observed in the other sub-basins. Elevated TSS was expected, due to the unbuffered bare ground at the development site. Interestingly, by reviewing the relative contributions of total phosphorus and soluble phosphorus (TP and SP, respectively), it was found that the overwhelming majority of phosphorus entering the lake from stream STR-1 was sediment bound (i.e., SP was nearly negligible). Reducing sediment inputs from this site, therefore, is expected to result in reduced phosphorus loading, as well. The best overall water quality observed during the storm event was at Site STR-2. The stream drains a relatively flat, small area and is not expected to contribute much to the sediment or nutrient load to Bixler Lake.

3.1.3 Phytoplankton

Results of phytoplankton identification and enumeration revealed a fairly diverse algal community, with a total of 23 species in four classes. The phytoplankton communities were numerically dominated by blue-greens (Table 3-4). At a depth of five feet (1.5 m), *Aphanocapsa pulchra* was prevalent while at 15 feet (4.6 m), *Aphanocapsa pulchra* and *Oscillatoria tenuis* were co-dominant. *Anabaena*, *Microcystis*, and *Aphanizomenon* also were numerically abundant. All three species are known to produce lethal toxins under certain conditions and can be associated with summer fish kills (Cole, 1979). In addition, all of these three species are associated with enhanced eutrophic conditions.

3.1.4 Sediments

Sediment core descriptions are presented in Table 3-5. Analytical results for TP, TKN, and volatile solids (VS) are listed in Table 3-6. Organic matter comprised the major portion of the sediment cores at all five in-lake stations. The dense communities of aquatic vegetation in these areas was believed to contribute to the accumulation of organic matter through the sloughing of leaves and stems. Cores from stations SED-1 and SED-2 contained loose plant detritus in the top layers, a finding consistent with the high TP and TKN values observed. The SED-3 core had a higher fraction of suspended sediment than the other cores. This condition is thought to be the result of an accumulation of sediment transported into the lake from the ditch, since fine material is expected to remain in suspension until it reaches the main body of the lake where water flow velocity is diminished. The relatively low VS, TKN, and TP values observed from this core sample were consistent with its high mineral/sediment content. The bottom layer, however, was composed of organic muck, indicating that the site had, at one time, been affected by macrophytes and accumulation of organic material. Cores from SED-4 and SED-5 had similar VS, TP, and TKN values. The relatively high values at these two stations were again indicative of the abundance of aquatic macrophytes in both sample areas. The top layers at both these sites consisted of decaying plant fragments. The bottom layer in SED-4 was sandy in texture and appeared to be representative of the original lake bottom.

TABLE 3-4. Results of phytoplankton identification and enumeration samples collected on 14 July 1989.

	SURFACE	THERMOCLINE
DEPTH OF SAMPLE (feet) (m)	5.00 1.52	15.00 4.57
SAMPLED WATER VOLUME (feet^3) (m^3)	3.60 0.10	10.81 0.31
SPECIES:	NUMBER OF CELLS (count in millions):	
Chlorophyta (green algae)		
Eudorina elegans	1.887	Scan
Gloeocystis planctonica	0.943	Scan
Scenedesmus bijuga	Scan	
Staurastrum paradoxum	0.472	
Pediastrum duplex reticulatum	Scan	
Chrysophyta (diatoms, chrysophytes)		
Fragilaria crotonensis	Scan	
Dinobryon divergens	12.029	3.440
Euglenophyta		
Phacus caudatus		Scan
Pyrrhophyta (dinoflagellates, cryptomonads)		
Ceratium hirundinella	4.717	16.555
Cyanophyta (blue-green algae)		
Anabaena flos-aquae	59.792	24.296
Anabaena planktonica	3.538	0.860
Anabaena spiroides	29.011	Scan
Aphanizomenon flos-aquae	46.112	54.827
Aphanocapsa pulchra	136.212	103.203
Chroococcus dispersus	0.353	Scan
Chroococcus dispersus minor	0.590	
Coelosphaerium dubium	Scan	Scan
Coelosphaerium kuetzinianum		5.160
Coelosphaerium sp.	70.759	Scan
Microcystis aeruginosa	76.656	Scan
Oscillatoria planktonica	5.779	1.290
Oscillatoria tenuis	Scan	221.671
Unidentified unicellular blue-green	2.359	

NOTE: "Scan" indicates species was observed during preliminary, nonquantitative scan.

Presently no guidelines exist for evaluating the importance of contaminant levels in aquatic sediments. The only criteria that are available are the standards that define hazardous waste and are used to determine the suitability of dredge spoils for disposal in hazardous waste landfills. Contaminant concentrations in aquatic sediments were determined by an Extraction Procedure (EP) toxicity test that simulated the leach potential

TABLE 3-5. Descriptions of sediment cores taken from Bixler Lake.

STATION	APPARENT VISUAL LAYER	EXTENT OF LAYERS (in)	(cm)	REMARKS
SED-1	Surface	1.5	3.8	Loose plant detritus at surface;
	Bottom	5.0	12.7	Patches of fine sediment in bottom; Entire core of loose consistency.
SED-2	Surface	3.0	7.6	Light tan, loose detritus at surface;
	Middle	10.0	25.4	Medium brown in mid-layer;
	Bottom	4.0	10.2	Black muck at bottom.
SED-3	Surface	2.5	6.4	Suspended sediments in tan overlying water; Fine grained, brown sediment top layer; Loose, black muck at bottom.
	Bottom	3.5	8.9	
SED-4	Surface	7.5	19.1	Black, grainy, mottled at top;
	Bottom	1.4	3.5	Brown, sandy at bottom.
SED-5	Surface	2.5	6.4	Decaying plant fragments at top;
	Middle	3.5	8.9	Black fine muck at mid-layer;
	Bottom	3.0	7.7	Gray-brown, granular on bottom.

TABLE 3-6. Results of sediment sample analysis for Bixler Lake.

STATION	TP (mg/l)	TKN (mg/l)	VS (mg/kg)
SED-1	311	1020	153000
SED-2	304	738	114000
SED-3	71	175	137000
SED-4	102	652	220000
SED-5	125	620	184000

of contaminants under conditions that might be expected to occur in a landfill. If the magnitude of EP-simulated leaching is greater than the established standards, the material is classified as a hazardous waste.

Results of the EP toxicity test performed on the sediment samples indicated that there were no contaminant concentrations above the established standards (Table 3-7). most of the analytes were below their detection limits.

TABLE 3-7. **Results of EP toxicity analysis of Bixler Lake sediment composites.**

PARAMETER	SED-1 (ppm)	SED-2 (ppm)	SED-3 (ppm)	SED-4 (ppm)	SED-5 (ppm)	Standard (ppm)
Arsenic	<0.001	<0.001	<0.001	<0.001	<0.001	5.00
Barium	<0.01	<0.01	<0.01	<0.01	<0.01	100.00
Cadmium	0.01	<0.01	<0.01	<0.01	<0.01	1.00
Chromium	0.02	0.03	0.05	0.01	0.06	5.00
Lead	<0.01	<0.01	<0.01	<0.01	<0.01	5.00
Mercury	<0.001	<0.001	<0.001	<0.001	<0.001	0.20
Selenium	<0.001	<0.001	<0.001	<0.001	<0.001	1.00
Silver	<0.01	<0.01	<0.01	<0.01	<0.01	5.00
Endrin	<0.001	<0.001	<0.001	<0.001	<0.001	0.02
Lindane	<0.001	<0.001	<0.001	<0.001	<0.001	0.40
Methoxychlor	<0.001	<0.001	<0.001	<0.001	<0.001	10.00
Toxaphene	<0.001	<0.001	<0.001	<0.001	<0.001	0.50
2,4-D	<0.001	<0.001	<0.001	<0.001	<0.001	10.00
2,4,5-T P	<0.001	<0.001	<0.001	<0.001	<0.001	1.00

Results of the depth to sediment, probe rejection depth, and sediment thickness measurements are presented in Table 3-8. Minimum values for all three parameters were found at station SED-3, a condition believed to be caused by increased deposition of inorganic particle originating from the bare-ground development site. The shoal of inorganic material observed at Station SED-3 was formed as incoming water slowed and deposited its sediment load, thereby decreasing the channel depth (i.e., depth to sediments). Because inorganic sediments are more dense than organic ones, probe rejection depth was reduced as compared to the other sites. Similarly, because sediment thickness was calculated as the difference between probe rejection depth and depth to sediments, the value for sediment thickness also decreased.

Analysis of sediment measurements at other stations revealed relatively consistent sediment coverage throughout the lake. This finding was attributed to the similar abundance of macrophytes (Section 3.1.6) in these areas. Macrophytes contribute to the organic content of sediments through sloughing and senescence of plant material. The plant beds also serve to diminish water flow velocity, increasing the potential for sediment deposition. Similar plant coverages would be expected to exert similar influences over sedimentation processes, thereby creating similar lake bottom conditions. In all likelihood, macrophytes were not a factor at the SED-3 site because their growth requirements (e.g., light incidence, nutrient availability, water depth) were overwhelmed by sediment influx. When the sediment inflows are reduced, however, the shoal may be expected to foster development of a dense plant community.

TABLE 3-8. Results of the sediment depth measurements taken at Bixler Lake.

STATION	DEPTH TO SEDIMENT (inches)	(cm)	REJECTION DEPTH (inches)	(cm)	SEDIMENT THICKNESS (inches)	(cm)
SED-1	41.3	105.0	116.1	295.0	74.8	190.0
SED-1A	55.1	140.0	143.7	365.0	88.6	225.0
SED-2	53.1	135.0	133.9	340.0	80.7	205.0
SED-3	37.4	95.0	10.0	25.5	62.9	160.0
SED-4A	51.2	130.0	133.9	340.0	82.7	210.0
SED-4	**********		***********		**********	
SED-5	**********		***********		**********	

Note: Asterisks indicate where probe was not long enough to take reading.

3.1.5 Bathymetry

Review of the bathymetric data collected for the project indicated that the maximum depth of Bixler Lake was 37 feet (11.3 m), as shown in Figure 3-2. The mean depth was 15.9 feet (4.8 m) and the volume was 8.23 X 10^7 cubic feet (2.33 X 10^6 m^3). Analysis of a bathymetric map produced by the Indiana Geological Survey (IGS, 1946) indicated that the lake had a maximum depth of 43 feet (13.1 m) in 1946. The mean depth and volume in 1946 were 16.6 feet (5.1 m) and 8.54 X 10^7 cubic feet (2.42 X10^6 m^3), respectively. Therefore, over the course of 43 years, Bixler Lake has lost approximately 6 feet (1.8 m) of maximum depth, 0.7 feet (0.2 m) of mean depth, and 3.09 X 10^6 cubic feet (8.76 X 10^4 m^3) of water storage volume. Further comparisons revealed that an accumulation of sediment has occurred throughout the lake. Differences in thickness are as much as 2 feet along the northwestern and southwestern sections of the lake, near the mouths of the tributaries. Changes in bathymetry are summarized in Table 3-9.

TABLE 3-9. Comparison of depth/volume values between 1946 and 1989 for Bixler Lake.

PARAMETER	1946 VALUE (feet)	(m)	1989 VALUE (feet)	(m)	NET LOSS (feet)	(m)
Maximum Depth	43.0	13.1	37.0	11.3	6.0	1.8
Mean Depth	16.6	5.1	15.9	4.8	0.7	0.2
Volume	8.54 X 10^7 cubic feet (2.42 X 10^6 m^3)		8.23 X 10^7 cubic feet (2.33 X 10^6 m^3)		3.09 X 10^6 cubic feet (8.76 X 10^4 m^3)	

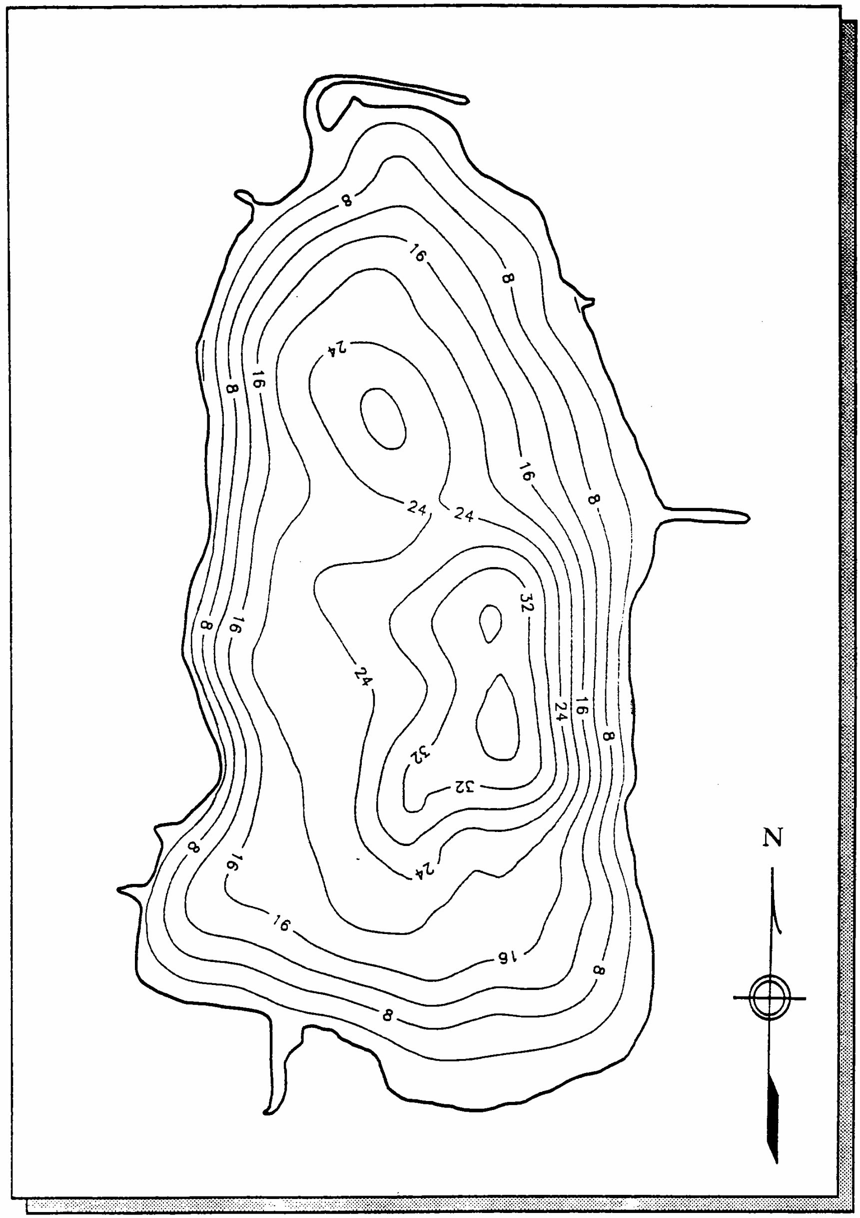

FIGURE 3-2. Bathymetric map of Bixler Lake in 1989. Depths are shown in feet.

3.1.6 Aquatic Vegetation

The aquatic vegetation survey documented a diverse range of macrophytes (Table 3-10) with the dominant emergent species being arrow arum (*Peltandra virginica*) and common cattail (*Typha latifolia*). Bur reed (*Sparganium chlorocarpum*) and pickerelweed (*Pontederia cordata*) were also observed. The predominant submergent species throughout the lake were coontail (*Ceratphyllum demersum*), Eurasian water milfoil (*Myriophyllum spicatum*), and American pondweed (*Potamogeton americanus*). Stonewarts (*Chara*) were present on the western shore. The most common floating species along the shores of Bixler Lake were yellow and white water lilies (*Nuphar variegatum* and *Nymphaea ordorata*, respectively). The ditch leading into the northern portion of the lake was occupied predominantly by American pondweed, Eurasian water milfoil, arrow arum, and two unknown species of blue-green algae. The blue-greens were present as filamentous mats on the surface of the water.

TABLE 3-10. List of macrophyte species found in Bixler Lake during the summer of 1989.

COMMON NAME	SCIENTIFIC NAME	HABITAT CLASS
Smartweed	*Polygonum natans*	Floating
White Water Lily	*Nymphaea ordorata*	Floating
Yellow Water Lily	*Nuphar variegatum*	Floating
Blue-green Algae	*Unknown*	Floating
Arrowhead	*Sagittaria sp.*	Emergent
Arrow Arum	*Peltandra virginica*	Emergent
Bur Reed	*Sparganium chlorocarpum*	Emergent
Common Cattail	*Typha latifolia*	Emergent
Pickerelweed	*Pontederia cordata*	Emergent
Coontail	*Cerataphyllum demersum*	Submergent
Eurasian Milfoil	*Myriophyllum spicatum*	Submergent
American Pondweed	*Potamogeton americanus*	Submergent
Stone Watts	*Chara sp.*	Submergent

Macrophyte stands at the mouths of the ditches were believed to be fostered by the development of shoals. Long-term consequences of shoals include decreased water depth, increased light availability for rooted plants, and increased accumulation of organic matter as macrophytes populate the shoal area. The macrophytes can undoubtedly cause navigational problems and increase the dominance of less desirable fish species in these areas. The lake may ultimately benefit from this situation, however. Dense stands of macrophytes will probably serve as a buffer to stream/ditch inflows, trapping nutrients and sediments that enter the lake with runoff. Aquatic plant coverage maps are presented in Figures 3-3a through 3-3c.

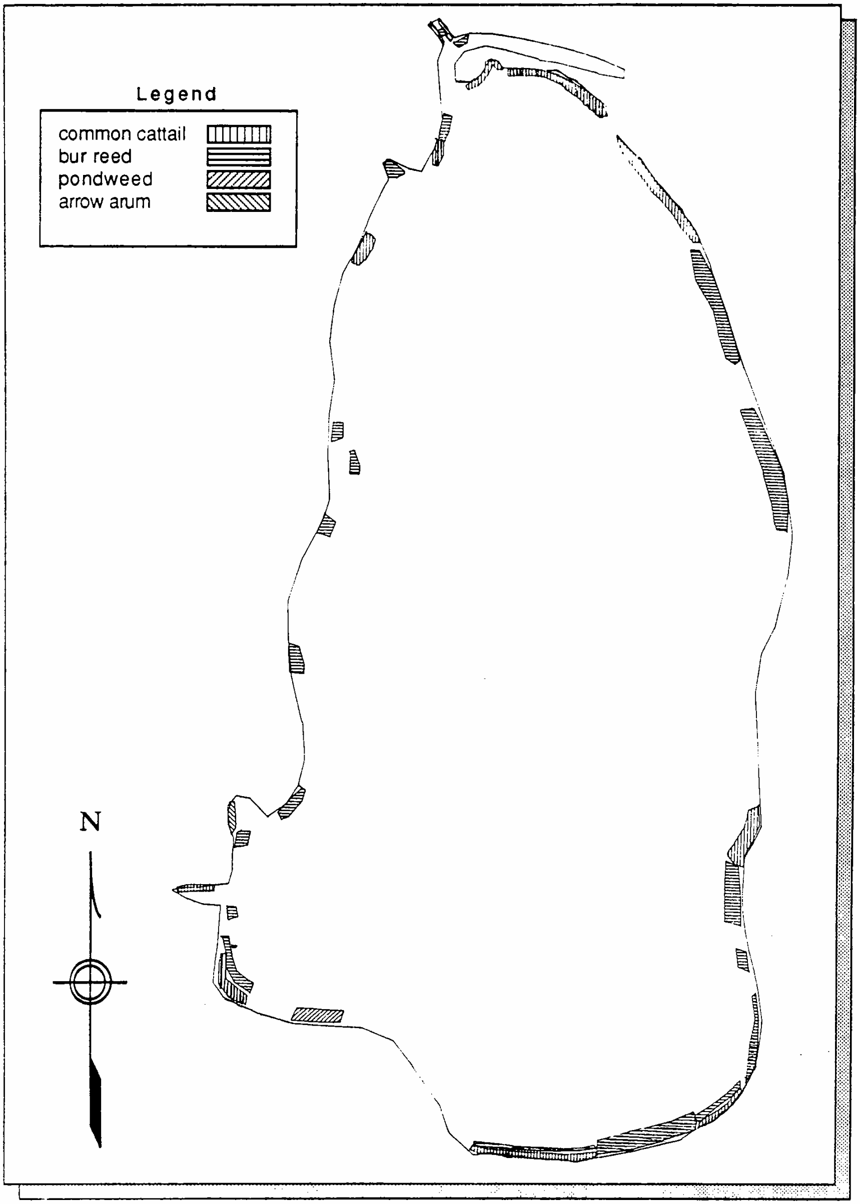

FIGURE 3-3a. Emergent macrophyte distribution in Bixler Lake.

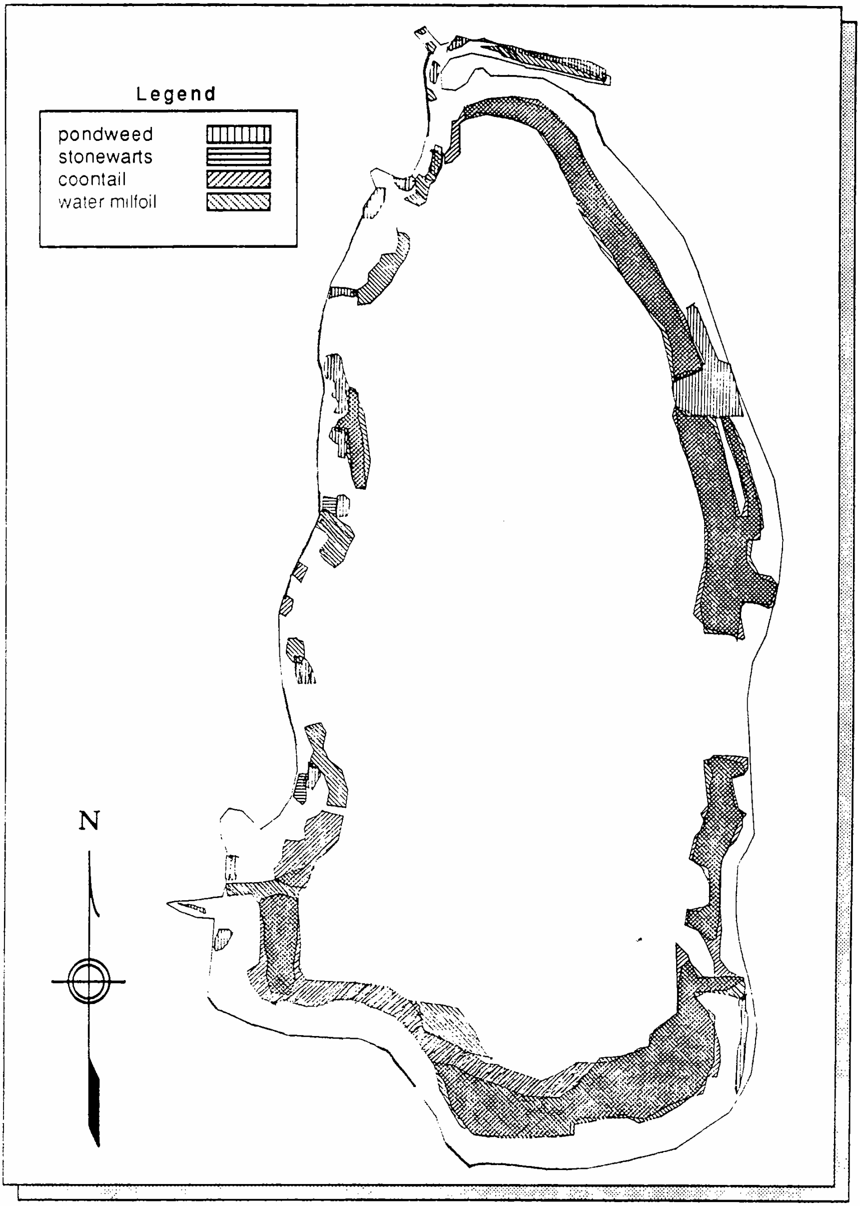

FIGURE 3-3b. Submergent macrophyte distribution in Bixler Lake.

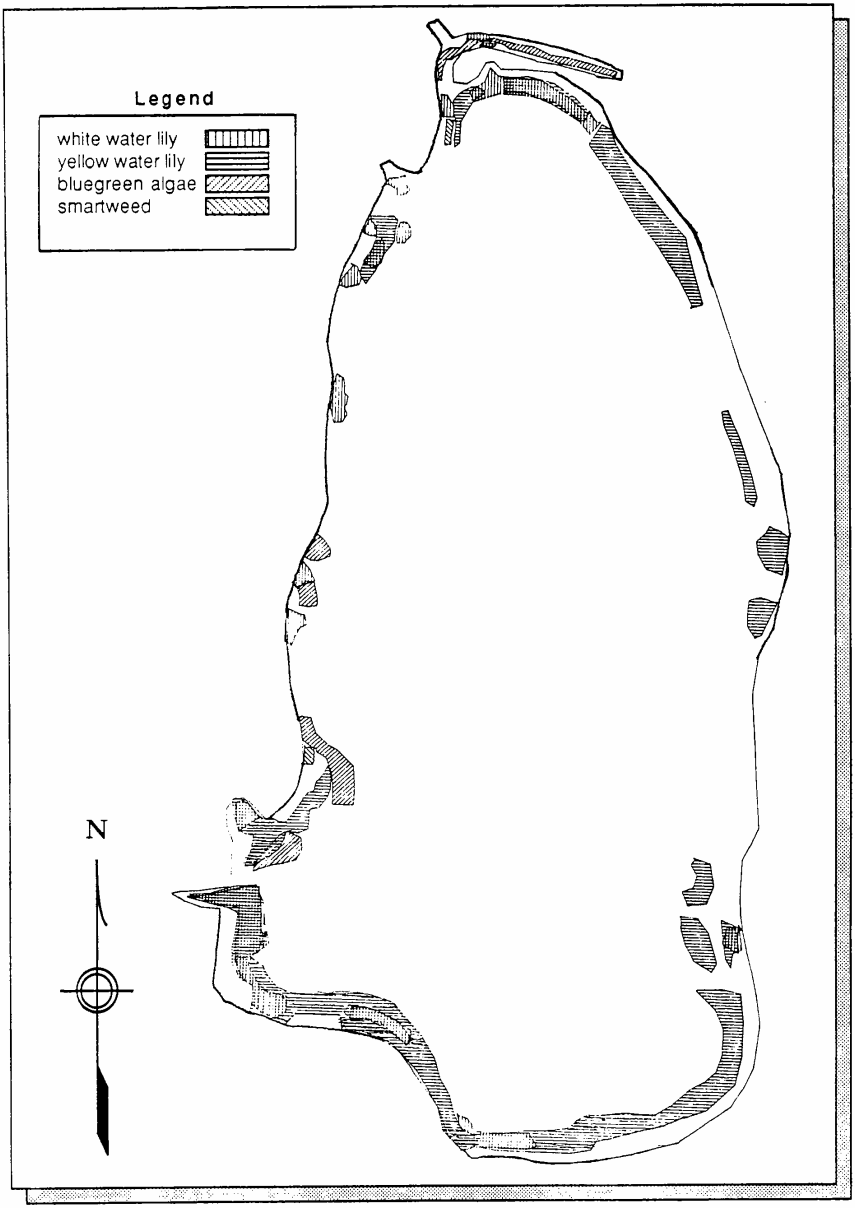

FIGURE 3-3c. Floating macrophyte distribution in Bixler Lake.

3.1.7 Trophic Index

Consistent with the lake categorization scheme outlined in the Indiana Lake Classification System and Management Plan (IDEM, 1986), a BonHomme Eutrophication Index (EI) was calculated for Bixler Lake. The index combines information about several diverse parameters into a single number intended to describe the degree of lake aging brought on by external inputs. Values are assigned for lake trophic parameters to give scores from 0 to 75, with values near 0 being the best (i.e., least eutrophic). Not only can this number be used to assess the degree of eutrophication within a single water body, it can also be used as a basis for comparing and establishing priorities for lakes for remediation throughout the state. It should be noted, however, that the data used to construct the EI are typically derived from a single sampling event and, therefore, only capture conditions as they existed on a single day in mid-summer. The index and calculations corresponding to data collected during this study are presented in Table 3-11.

The EI for Bixler Lake was calculated to be 28 points, placing the water body in the "Class Two" category within the IDEM scheme. These lakes are described as "productive and slowly moving toward senescence." They often support extensive concentrations of macrophytes and/or algae but not at levels that severely impair beneficial uses (e.g., fishing, swimming). Most Indiana lakes fall into this category. It should be noted that IDEM previously derived an EI of 38 for Bixler Lake, 10 points higher than the value determined in this study. The difference is probably explained by the temporally variable nature of physical, chemical, and biological conditions during different sampling events. Greater utilization of best management practices and the recent dry summers may have also played a role.

In 1986, IDEM revised the Indiana Lake Classification and Management Plan, separating lakes into distinct "management groups." This categorization was in addition to the "Class Two" distinction, noted above. The management groups were derived using a cluster analysis procedure that compared and grouped Indiana lakes on the basis of EI value, mean depth, and surface area. In the IDEM report and in this study, Bixler Lake was assigned to the "Group VI-A" management set. This classification generally designates water bodies that exhibit moderate to advanced eutrophication but not to the point where large-scale restoration measures are warranted. Applicable management techniques will be described in Section 4 of this report.

3.1.8 Fisheries

Analysis of fishery history in Bixler Lake centered on information obtained through the literature search. Pearson (1988) conducted a fishery survey of the lake to evaluate the nature of fish populations in the water body. He found that bluegills (*Lepomis macrochirus*) dominated the catch by number (52%) and carp (*Cyprinus carpio*) dominated by weight (48%). Other important game species recorded during the survey included largemouth bass (*Micropterus salmoides*), yellow perch (*Perca flavescens*), black crappie (*Pomoxis nigromaculatus*), and channel catfish (*Ictalurus punctatus*).

Based on his results, and on those of previous studies, Pearson concluded that carp populations were expanding and could reach nuisance levels in a few years. This finding has serious implications for water quality management in Bixler Lake because carp cause

TABLE 3-11. **Eutrophication index calculations performed on data collected from Bixler Lake on 14 July 1989.**

PARAMETER AND RANGE	RANGE VALUES	RANGE OBSERVED	POINT VALUE
Total Phosphorus (mg/l)			
At least 0.03	1		0
0.04 to 0.05	2		0
0.06 to 0.19	3	X	3
0.20 to 0.99	4		0
Greater than 0.99	5		0
Soluble Phosphorus (mg/l)			
At least 0.03	1		0
0.04 to 0.05	2		0
0.06 to 0.19	3	X	3
0.20 to 0.99	4		0
1.0 or more	5		0
Organic Nitrogen (mg/l)			
At least 0.50	1		0
0.60 to 0.80	2		0
0.90 to 1.90	3		0
2.0 or more	4		0
Nitrate (mg/l)			
At least 0.3	1		0
0.40 to 0.80	2		0
0.90 to 1.90	3		0
2.0 or more	4		0
Ammonia (mg/l)			
At least 0.30	1		0
0.40 to 0.50	2	X	2
0.60 to 0.90	3		0
1.0 or more	4		0
Percent oxygen saturation at 5 feet			
114% or less	0	X	0
115% to 119%	1		0
120% to 129%	2		0
130% to 149%	3		0
150% or more	4		0

significant disturbances to lake bottoms and desirable plants beds. Moreover, their activities tend to create higher turbidity in the water column which can lead to stimulated algal growth and declining dissolved oxygen conditions. These disruptions could eventually offset many of the improvements gained by upland watershed controls suggested in a later section of this report. Currently, however, carp populations are not at levels that call for immediate action (i.e., eradication). Pearson suggested that another fishery survey be conducted in the early 1990s to monitor carp expansion. Management efforts should be based on the results of such a study.

TABLE 3-11 (continued). Eutrophication index calculations performed on data collected from Bixler Lake on 14 July 1989.

PARAMETER AND RANGE	RANGE VALUES	RANGE OBSERVED	POINT VALUE
Percent of Water Column with at least 0.1 ppm DO			
28% or less	4		0
29% to 49%	3	X	3
50% to 65%	2		0
66% to 75%	1		0
76% to 100%	0		0
Secchi Disk Transparency			
5 feet or less	6		0
greater than 5 feet	0	X	0
Light Transmission at 3 Feet			
0% to 30%	4		0
31% to 50%	3		0
51% to 70%	2	X	2
71% or greater	1		0
Total Plankton from 5 foot Tow (#/ml)			
Less than 500/ml	0		0
500/ml to 999/ml	1		0
1000/ml to 1999/ml	2		0
2000/ml to 2999/ml	3		0
3000/ml to 5999/ml	4	X	4
6000/ml to 9999/ml	5		0
10000/ml or more	10		0
Blue-green dominance	5 additional points	X	5
Total Plankton from Thermocline Tow (#/ml)			
Less than 1000/ml	0		0
1000/ml to 1999/ml	1	X	1
2000/ml to 4999/ml	2		0
5000/ml to 9999/ml	3		0
10000/ml to 19999/ml	4		0
20000/ml to 29999/ml	5		0
30000/ml or more	10		0
Blue-green dominance	5 additional points	X	5
Populations of 100000 or more	5 additional points		0
INDEX VALUE			28

3.2 WATERSHED SURVEY RESULTS

The findings of the watershed survey are presented in this subsection. Topics addressed include climate, hydrology, soils, and land use. It is critical to understand these characteristics because they influence the dynamics of water, sediment, and nutrients associated with the lake. The results of the AGNPS modeling exercise are also addressed because the computer was an important tool for integrating the effects of these factors and interpreting their significance.

3.2.1 Climate

Climate is often considered a "master variable" in controlling the condition of inland water bodies. It drives the hydrologic cycle, directly governing hydrologic inputs such as rainfall and outputs such as evaporation. It affects soil moisture conditions and plant growth which in turn influence the potential for surface water losses through evapotranspiration and infiltration. Runoff and stream flow, therefore, are also dependent on the weather. Factors to consider when analyzing climate include:

- Type of precipitation
- Timing of precipitation
- Duration of precipitation
- Direction of storm movement
- Temperature
- Solar energy input

Selected monthly climatic data for the Bixler Lake region are listed in Table 3-12. Discussion of the weather characteristics for the area is presented below. Information for this report was produced using data from a computerized weather generator (Nick and Lane, 1988), the Soil Conservation Service (USDA, 1977), and the Weather Atlas of the United States (DOC, 1968).

The climate of Noble County, influenced both by cool Canadian air masses from the north and by humid, semitropical air masses from the south, can be generally described as continental, although there is modification from the Great Lakes. Average winter temperatures range between a minimum of 18.7° F (-7.4° C) and a maximum of 34.7° F (1.1° C). Average summer temperatures range between a minimum of 60.2° F (15.7° C) and a maximum of 81.9° F (27.7° C). Relative humidity at noon is usually near 55% in the summer and 65% in the winter. On most nights, however, relative humidity increases to 95-100%. Dew and frosts are common.

Solar radiation ranges between an average minimum of 111 Langleys per day in December and a maximum of 528 Langleys per day in June. The annual mean is 324 Langleys per day. The sun is observed for 58% of the daylight hours, including approximately 37% in December and 72% in July. An average of 77 days are completely clear each year, and 181 days are overcast. The remainder are either partly sunny or partly cloudy.

Precipitation is evenly distributed throughout the year (Figure 3-4), with a monthly average rainfall of 2.98 inches (7.57 cm). Spring and early summer rains generally exceed

TABLE 3-12. **Selected climatic data for the Bixler Lake watershed.**

Month	Precip (In)	Precip Durat (Hour)	Max Temp (°F)	Min Temp (°F)	Solar Radiat (Ly/Day)
January	2.47	17.6	33.3	17.3	123.6
February	2.55	16.3	35.4	18.4	195.7
March	2.79	20.8	45.4	26.5	293.2
April	4.03	22.0	58.0	37.0	372.2
May	3.75	17.8	69.9	47.9	467.6
June	3.29	12.0	79.4	58.3	528.3
July	3.61	15.5	84.2	62.6	520.2
August	2.68	13.9	82.0	59.6	467.1
September	2.46	14.5	75.0	53.6	384.2
October	3.24	14.1	63.5	42.9	271.3
November	2.93	16.2	46.8	30.1	157.7
December	1.99	18.0	35.5	20.4	111.1
AVERAGE	2.98	16.6	59.0	39.6	324.4
TOTAL	35.79	198.6			

precipitation levels during the rest of the year and are considered reliable for ensuring excellent crop growing conditions. Average duration of storms is approximately 16.6 hours, with a minimum of 12.0 hours in June and a maximum of 22.0 hours in April. The mean annual rainfall is 35.8 inches (90.9 cm). Annual snowfall averages 27.0 inches (68.6 cm).

Winds are generally out of the southwest at 8 miles per hour in summer, and out of the northwest at 12 miles per hour in winter. Therefore, summer storms traverse the Bixler Lake watershed from southwest to northeast and runoff concentrates first from the southwestern sections of the catchment. Winter storms travel from northwest to southeast but often bring snow rather than rain and, thus, runoff concentration is less of an issue. The only damaging winds arise from thunderstorms or tornadoes, although tornadoes are quite rare. Thunderstorms occur about 46 days of the year.

Investigation of precipitation chemistry in this study focused on plant nutrients (i.e., nitrogen and phosphorus) in an attempt to quantify atmospheric loading of these factors. Although information on the subject was scarce, data were found for two monitoring stations within a reasonable distance of Bixler Lake: Benton Harbor, Michigan and Put-in Bay, Ohio. Interpolated averages were found for total phosphorus (0.07 mg/l), nitrate (0.45 mg/l), and ammonia (1.18 mg/l). Data were unreliable for total nitrogen. Combining these averages with annual atmospheric water loading yielded estimates for atmospheric nutrient loading. Annual atmospheric loading was calculated to be 66.5 pounds/year (30.2 kg/yr) of total phosphorus, 427 pounds/year (194.0 kg/yr) of nitrate-nitrogen, and 1121 pounds/year (508 kg/yr) of ammonia-nitrogen.

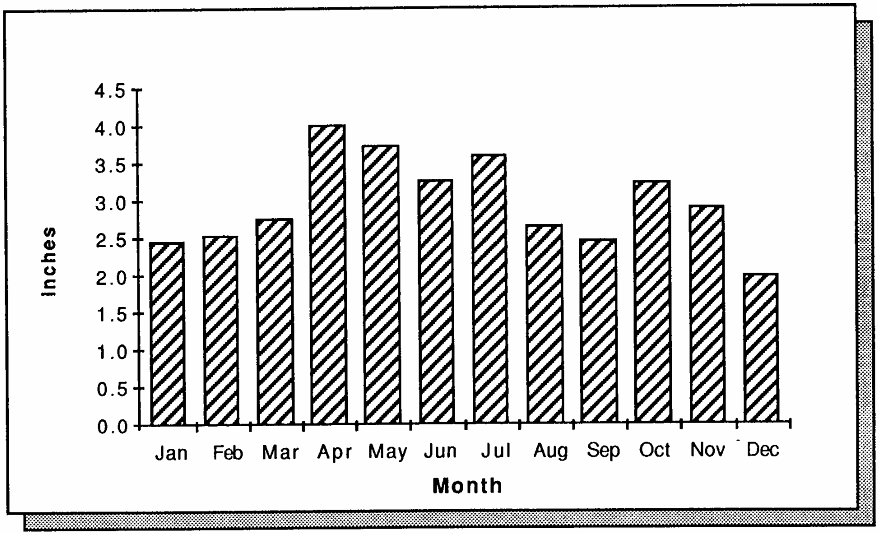

FIGURE 3-4. Monthly distribution of precipitation in the Bixler Lake watershed.

Although these figures formed the basis for assessing atmospheric nutrient loading, the supporting data were gathered at considerable distances from Bixler Lake and a large degree of uncertainty accompanies them. In particular, phosphorus concentrations in rainfall may be considerably higher in Noble County than indicated by these figures. Intensive row crop agriculture is practiced in many areas of the County and tends to contribute large amounts of particle-bound phosphorus to the atmosphere in the form of dust. Such areas generally experience increased phosphorus levels in precipitation.

3.2.2 Hydrology

Another "master variable" controlling the condition of water bodies is the physical layout of the drainage basin. The general topographic attributes of the catchment area influence the behavior of water once it reaches the ground. In conjunction with climate, hydrologic qualities affect runoff volume (i.e, mass input), velocity (i.e., erosional capacity), and timing (i.e., flood potential). Important aspects of a watershed investigation include consideration of the following features:

- Basin area
- Catchment shape
- Slope
- Geographic orientation
- Drainage pattern

Characterization of hydrologic features for this study focused on two types of analyses: (1) a general description of watershed morphological attributes, and (2) calculation of an approximate mass-balance water budget. Appropriate discussion of the components of each analysis are included.

The Bixler Lake watershed covers approximately 3524 acres (1426 ha) and is irregularly shaped (Figure 3-5). Its longitudinal axis runs from southwest to northeast lending an appearance of "tilt" to the catchment outline. Its gravitational center is situated almost 0.4 miles (0.6 km) due south of the lake, just outside the boundary of Bixler Lake Park. The perimeter of the watershed is roughly 13.2 miles (21.2 km) and, with respect to its longitudinal axis, constricted in the middle and flared at each end. The most distant point of the basin lies nearly at its southern tip, close to the intersection of Route 3 and the 350 North Road. This point is approximately 2.5 miles (4.0 km) from the lake overflow and constitutes the endpoint of the watershed's "axial length." The average width of the basin, defined as the ratio of catchment area to axial length, is 2.2 miles (3.6 km). These and other key morphological parameters are presented in Table 3-13. Discussion of the significance of pertinent indices follows.

The slope of a drainage basin has an important and complex role influencing infiltration, runoff, soil moisture, and groundwater contribution to stream flow. It is one of the major factors governing the time required by overland flow to reach channels where it is quickly transferred downstream (i.e, time of concentration). Greater slopes generally increase runoff velocity, thereby decreasing time of concentration. Elevated runoff velocity is also accompanied by diminished infiltration and enhanced erosional capacity. The Bixler Lake watershed has an average slope 4.0%, reflecting the relatively flat topography of the region. The minimum slope, 0.5%, occurs adjacent to the southern shore of the lake and

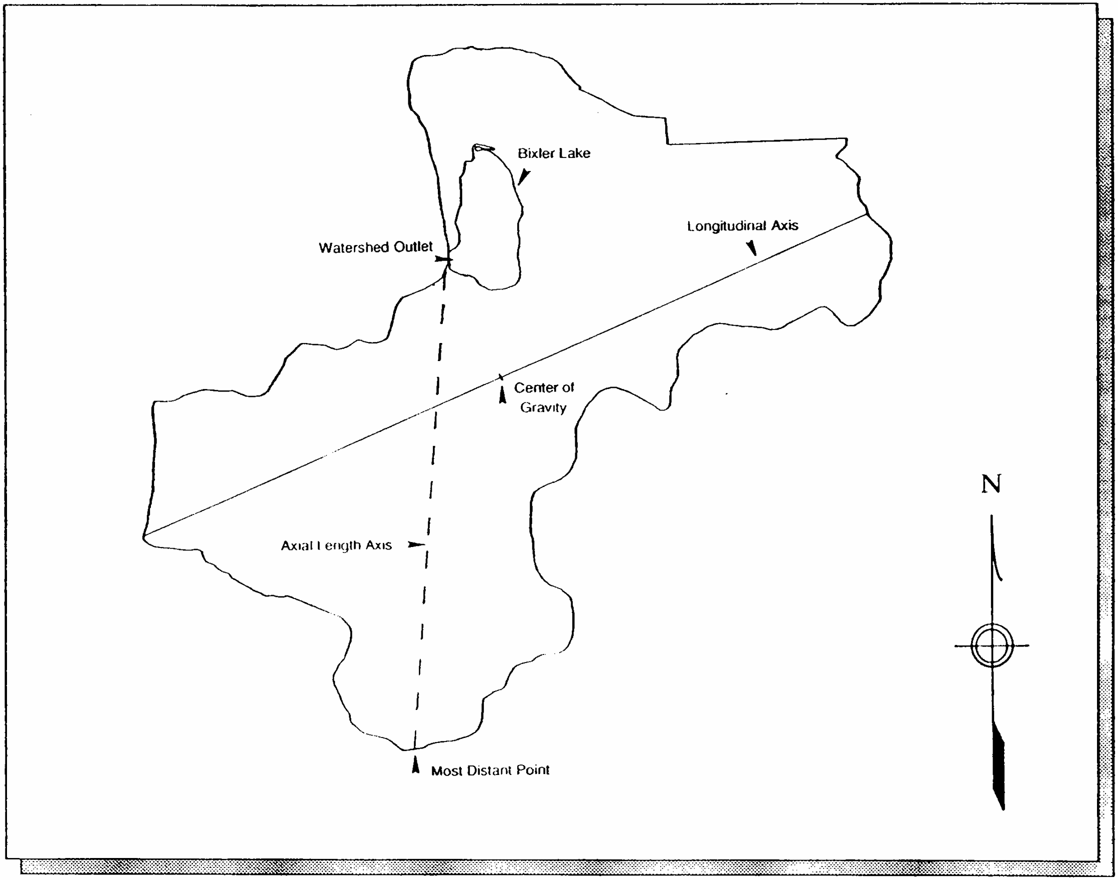

FIGURE 3-5. Outline and pertinent features of the Bixler Lake watershed.

TABLE 3-13. **Morphological features of the Bixler Lake watershed.**

ATTRIBUTE	TRADITIONAL VALUE	METRIC VALUE
Area	3524 acres	1426 ha
Perimeter	13.2 miles	21.2 km
Axial Length	2.46 miles	3.96 km
Average Width	2.24 miles	3.60 km
Average Slope	4.0 %	same
Minimum Slope	0.5 %	same
Maximum Slope	7.7 %	same
Form Factor	0.91 (unitless)	same
Compactness Coeff.	1.58 (unitless)	same
Eccentricity	0.99 (unitless)	same
Drainage Density	1.04 miles/mile^2	0.65 km/km^2

is evident in the extensive wetland areas that are present there. The maximum slope, 7.7%, occurs along the southeastern border of the northern half of the watershed and is manifest in several well-defined stream channels and ponds found in that area. The elevation of the basin ranges from 964 feet (294 m) at the lake to 1050 feet (320 m) near the settlement of Lisbon.

Another consideration in characterizing the hydrologic components of the Bixler Lake watershed is basin orientation. Orientation, often called "aspect", refers to the compass direction toward which most of the slopes in the catchment face. Since the lake itself is situated in nearly the northernmost portion of the watershed, most slopes face northward. This orientation is important, especially in winter, because snow on these slopes is not subjected to the most direct angle of solar incidence and, therefore, does not melt as quickly as snow on southern exposures. Snow cover tends to build up in these areas, storing a considerable amount of moisture until early spring thaws. When snow melt does occur, the stored water is released, emulating the effects of a large rainfall event developing over a relatively short time. Higher stream flows can be expected in the early spring.

The shape of a drainage basin governs the rate at which runoff is supplied to the catchment's main water body following a precipitation event. Although it is difficult to adequately express shapes by using numerical indices, three such measures were calculated for the Bixler Lake watershed: (1) form factor, (2) compactness coefficient, and (3) eccentricity. Being the ratio of average width to axial length, the form factor is an indicator of the relative elongation of the catchment. Basins with form factors that approach 1.0 are said to be uniform and non-elongated. Compared to an elongated area, this type of watershed is more likely to have intense or lengthy rainfall over its entire extent. The resulting runoff tends to reach streams and lakes from all points in the basin simultaneously and, therefore, watersheds with form factors near 1.0 are usually considered prone to high flood peaks. The Bixler Lake watershed has a form factor of 0.91 and, using this criteria alone, normally would be classified as non-elongated and likely to experience high flood peaks.

The second shape index estimated for the Bixler Lake basin was the compactness coefficient (CC). The CC is a test for uniform shape that compares the perimeter of the watershed with the perimeter of a circle of equal area. Catchments with CC values that approach 1.0 are nearly circular while those with CC values that diverge from 1.0 are more complex. Being uniform, circular watersheds tend to contribute runoff simultaneously and, thus, are also prone to elevated flood peaks resulting from intense or lengthy rainfall events. The Bixler Lake catchment has a CC value of 1.58, indicating a somewhat non-circular shape. This finding is due to the "constricted" middle portion of the watershed and implies that the basin is not as prone to floods as review of the form factor alone would suggest. A result of 1.58 does not, however, represent a major departure from uniformity and the watershed can be expected to sustain elevated flood peaks.

The third shape index used in this study was watershed eccentricity, a measure relating watershed shape to that of an ellipse. Again, the premise behind eccentricity calculation is that flood peaks are higher in more rounded catchments rather than in more elongated ones. Eccentricity values that approach 0.0 indicate a rounded shape and, thus, are usually associated with high flood peaks. Conversely, values that approach infinity are associated with low flood peaks. In empirical studies of uniform storms covering an entire watershed, this index has been found to be more accurate than either the form factor or the compactness coefficient. The Bixler Lake basin has an eccentricity value of 0.99, indicating moderately high flood peak potential.

Another important characteristic of any watershed is the arrangement of the streams that drain it. The efficiency of the drainage system and, therefore, the characteristics of flood peaks are directly dependent on this attribute. Generally, if a basin is well-drained and the length of overland flow is short, surface runoff concentrates rapidly and contributes to a high flood peak. Average flows are usually low in such systems. One measure of drainage efficiency used in this study is termed "drainage density." Being the ratio of total length of perennial channels to total watershed area, this index provides an indication of basin stream coverage. The Bixler Lake watershed has a drainage density of 1.04 miles/square mile (0.64 km/km^2) and, using this criteria alone, would be considered well-drained and prone to flash flood flows. This tendency is mitigated somewhat by long overland flow (not computed) and deep, infiltratable soils (Section 3.2.3). The pattern of the drainage network can be described as dendritic.

An annual water budget was computed for the Bixler Lake watershed using the climatic and hydrologic data discussed above. Water budget components included information on inputs (e.g., direct rainfall, runoff, and springs) and outputs (e.g., evaporation, overflow, and leakage). These components are summarized in Table 3-14. The total calculated volume of water input to Bixler Lake was 1.81 X 10^8 cubic feet (5.13 X 10^6 m^3). Of this amount, 91.7% was attributed to runoff from the catchment (including stream flow) and 8.3% was attributed to direct rainfall on the lake surface. Of the outputs, lake overflow constituted 92.8% of the total, while evaporation accounted for 7.2%. Hydraulic retention time, the ratio of lake volume to inflow volume, was estimated to be 0.45 years, indicating a rapid turnover of water in Bixler Lake. Retention times of less than 1 year are fairly common for lakes in the northeastern part of the state.

TABLE 3-14. **Components of the Bixler Lake water budget.**

ANNUALIZED RAW DATA:

ATTRIBUTE	TRADITIONAL VALUE	METRIC VALUE
Watershed Area	3524 acres	1426 ha
Lake Surface Area	117 acres	47.4 ha
Rainfall	35.8 inches	90.9 cm
Runoff	13.5 inches	34.2 cm
Pan Evaporation (raw)	41.3 inches	104.9 cm
Pan Coefficient	0.77 inches	1.9 cm
Pan Evaporation (adjusted)	31.6 inches	80.3 cm
Potential Evapotranspiration	34.6 inches	88.0 cm

ANNUALIZED WATER BUDGET DATA:

INPUT PARAMETER	TRADITIONAL VALUE	METRIC VALUE
Rainfall	1.52×10^7 cubic feet	4.31×10^5 m^3
Runoff	1.66×10^8 cubic feet	4.70×10^6 m^3
Groundwater[a]	0.00×10^1 cubic feet	0.00×10^1 m^3
TOTAL INPUTS	1.81×10^8 cubic feet	5.13×10^6 m^3

OUTPUT PARAMETER	TRADITIONAL VALUE	METRIC VALUE
Evaporation (adjust)	1.34×10^7 cubic feet	3.81×10^5 m^3
Lake Overflow[b]	1.68×10^8 cubic feet	4.75×10^6 m^3
Groundwater[a]	0.00 cubic feet	0.00 m^3
TOTAL OUTPUTS	1.81×10^8 cubic feet	5.13×10^6 m^3

HYDRAULIC RETENTION DATA:

PARAMETER	TRADITIONAL VALUE	METRIC VALUE
Lake Volume	8.23×10^7 cubic feet	2.33×10^6 m^3
Inflow Volume	1.81×10^8 cubic feet	5.13×10^6 m^3
Hydraulic Retention	0.46 years	same

[a] Assumed to be 0 due to unavailability of data.

[b] Calculated as the residual of (inputs - evaporation).

An additional component of water resource study is potential evapotranspiration (PET). Used as a measure of the maximum possible evaporation through the soil and vascular plants, analysis of PET provides an indication of water losses from the surface flow regime. On a practical level, calculation of this parameter forms the basis of determining local crop suitability, irrigation requirements, and reservoir design needs. An important subtraction of water from a drainage basin, evapotranspiration dominates the water balance and controls many non-surface phenomena including soil moisture content and groundwater recharge.

Potential evapotranspiration in the Bixler Lake watershed was calculated at 34.6 inches (88.0 cm) per year, approximately one inch less than the annual rainfall. Actual evapotranspiration was, of course, much smaller than this estimate, as evidenced by the 13.5 inches (34.2 cm) of annual runoff in the basin. True evapotranspiration, if calculated as a percentage of the residual of rainfall minus runoff (i.e., infiltration), was probably less than 22.3 inches (56.7 cm) and limited by soil and climatic conditions. For example, in some soils, moisture percolates rapidly to the water table and is incorporated in groundwater below the reach of plants and other evaporative mechanisms. Climate exerts an influence both during rainy and dry periods, when there is alternately too much or too little water to supply the removal process. Though not a direct surrogate for true evapotranspiration, PET indicates the magnitude of potential water losses, given a uniform and non-limited water reserve. The high PET value for Bixler Lake was not considered unusual.

3.2.3 Soils

The soils in Noble County formed from glacial till, glacial outwash, alluvium, and organic material as the area was covered several times during successive ice-ages. The glacial drift, till, and outwash deposits in the county range in depth from 200 feet in the southwest to 450 feet in the northeast (Wayne, 1956). Bixler Lake lies in an area of deep glacial deposits. Although Noble County contains 8 different soil associations (i.e., distinct proportional patterns of soil types), the Bixler Lake Watershed is almost entirely comprised of only three. These associations are:

1. **Miami-Riddles-Brookston association:** These soils are highly variable within the watershed, ranging from well-drained to very poorly-drained, nearly level to moderately steep. They are deep soils that have a moderately fine textured subsoil and are found primarily on uplands. This association is used mostly for crops and pasture.

2. **Houghton-Edwards-Adrian association:** These soils are very poorly-drained, nearly level mucks that are deep or moderately-deep over marl or sand and gravel. They are found primarily in depressions or outwash plains. Drained areas of this association are used mostly for crops while undrained areas are mostly under wetland plant cover.

3. **Morley-Blount association:** These soils are well-drained to somewhat poorly-drained, nearly level to moderately sloping assemblages. They are deep soils that have a moderately fine textured subsoil and are found primarily on uplands. This association is used mostly for crops.

It should be noted that grouping soils into associations is helpful only for broad, interpretative purposes. The soils in any one association ordinarily differ in slope, depth, stoniness, drainage, and other characteristics that affect their management.

Highly erodible soils, as defined by the Noble County Soil and Water Conservation District (NCSWCD, 1987), are quite common in the Bixler Lake watershed. Nearly two-thirds of the basin experiences extensive sheet, rill, and gully erosion as depicted in Figure 3-6. In Noble County, annual sediment losses due to all sources of erosion have been estimated to be as high as 13.1 tons/acre (29361 kg/ha), but average 11.1 tons/acre (24878 kg/ha). This condition is not only damaging to crops and agricultural production, but also holds serious implications for water resource management. Since approximately 20% of the erosional load (i.e., 338,000 tons, county-wide) is deposited in waterways each year, it is clear that Bixler Lake is at risk from sedimentation.

3.2.4 Land Use

One of the most influential factors governing the longevity and quality of a surface water body is the nature of land use in the drainage basin. Land use categorization within the Bixler Lake watershed was critical in determining input parameters for the AGNPS model. The sixteen different land use categories and corresponding areal coverages are listed in Table 3-15. A color land use map is presented in Figure 3-7.

TABLE 3-15. **Land use areas/percentages for the Bixler Lake watershed.**

CATEGORY	WATERSHED AREA (acre)	(ha)	WATERSHED PERCENT
Water	159.6	64.6	4.5
Wetlands	141.5	57.3	4.0
Forest	604.7	244.7	17.1
Open	199.8	80.9	5.7
Pasture	20.1	81.2	0.6
Row Crops	1251.5	506.4	35.5
Non Row Crops	223.8	90.6	6.4
Orchard	3.5	1.4	0.1
Feedlot	0.0	0.0	0.0
Low Density Residential	110.6	44.7	3.1
Medium Density Residential	135.8	54.9	3.9
High Density Residential	90.7	36.7	2.6
Commercial	133.0	53.8	3.8
Institutional	147.2	59.6	4.2
Bare Ground	26.8	10.8	0.8
Construction	171.7	69.5	4.9
Non-categorized	104.2	42.2	3.0
TOTALS	3524.4	1426.3	100.0

The primary land use within the Bixler Lake watershed was row crop agriculture, accounting for 35.5% of the total area. Blocks of row crops were dispersed uniformly throughout the watershed, although areas in the southwestern section of the catchment contained the highest densities. Forested land constituted 17.2% of the watershed and, although present throughout the basin, the majority was located along the perimeter of

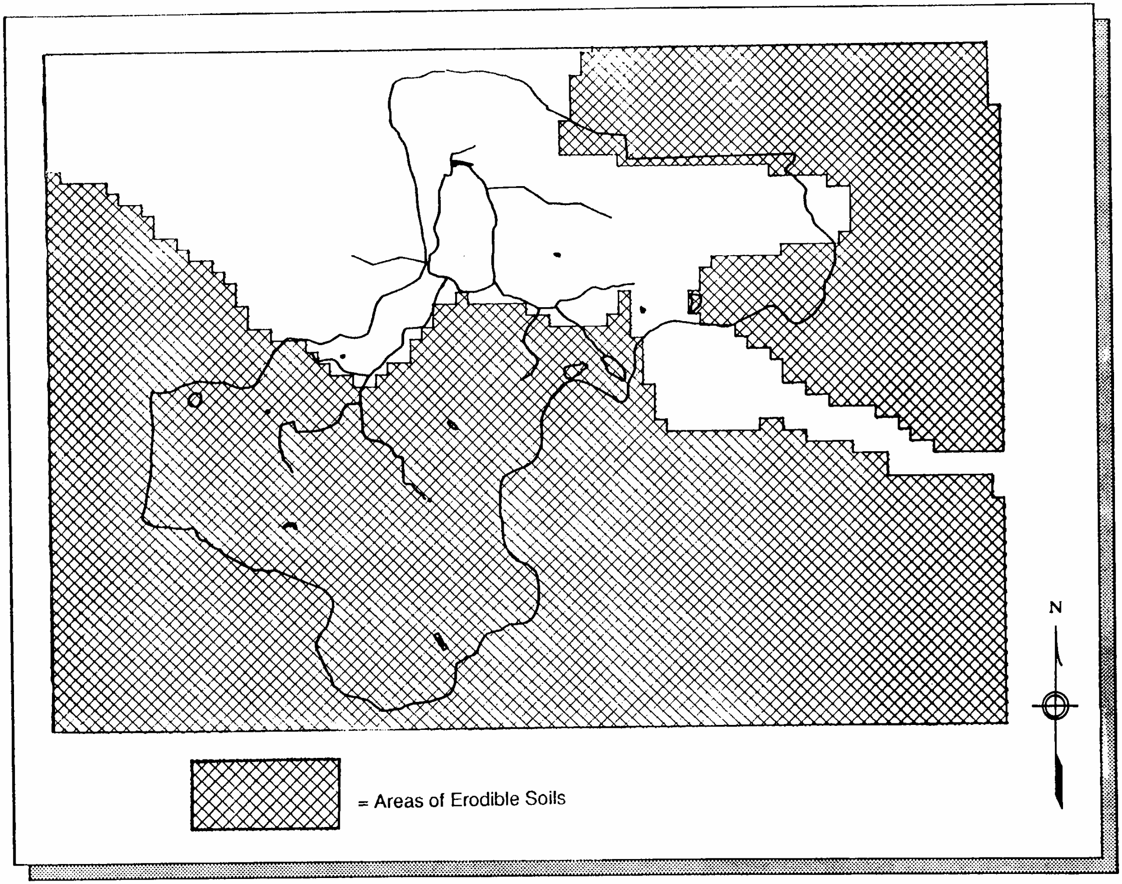

FIGURE 3-6. Erodible soil coverages with the Bixler Lake watershed.

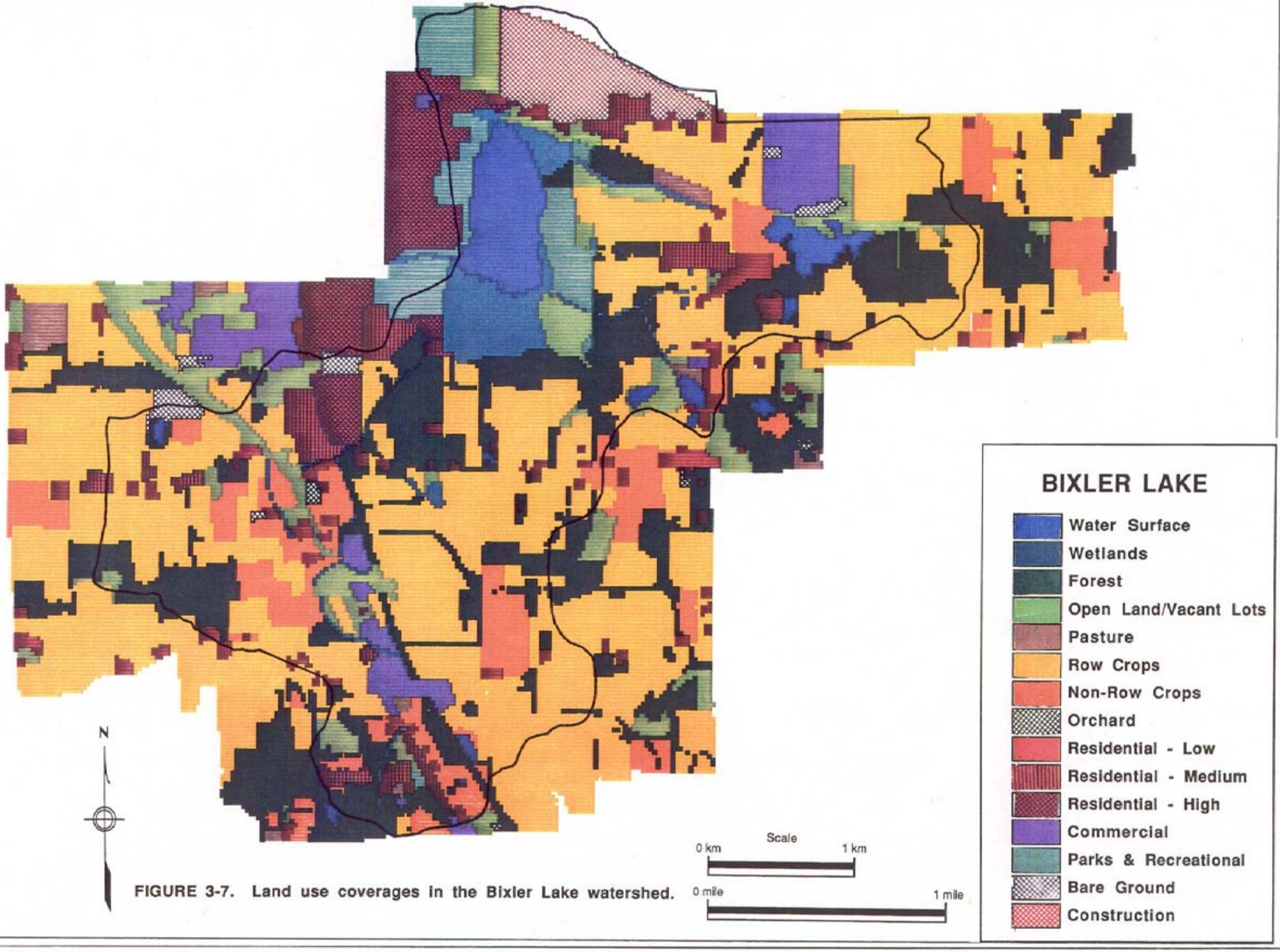

FIGURE 3-7. Land use coverages in the Bixler Lake watershed.

Bixler Lake. The three residential use categories cumulatively accounted for 9.56% of the area and were distributed with the largest concentrations occurring directly south of Kendallville on either side of Main Street. This area included a high density trailer park adjacent to one of the tributary streams feeding Bixler Lake. Although comprising only 4.87% of the watershed, construction activities in the watershed were located directly north and east of the lake and presented a potentially damaging source of sediment and nutrient loading.

3.2.5 Modeling Results

In using the AGNPS model, it was necessary to divide the watershed into a grid of homogeneous areas, called "cells" (Figure 3-8). Data characterizing the physical features of the cells were utilized by the model to describe the sediment and nutrient contributions of each cell. This information was used to identify cells that were responsible for disproportionate sediment and nutrient export to the lake. Four categories of AGNPS output were evaluated in describing the pertinent export features: (1) sediment yield; (2) cell erosion; (3) nutrient loading; and (4) hydrology. The AGNPS model was run on two distinct scenarios. The first described the watershed prior to the conversion of land in the northwest section of the catchment from agricultural land use to open construction. The second described the situation after the conversion. The following discussion summarizes the AGNPS output from each of the four categories (i.e., sediment yield, cell erosion, nutrient loading, and hydrology) for the watershed both before and after construction.

Sediment Yield and Erosion

Sediment yield from each AGNPS cell is the amount of sediment, in tons, that leaves a cell at its downstream edge. This figure represents not only the sediment generated inside the cell but also the sediment generated in upstream cells. It is important to note that AGNPS also accounts for sediment deposition within a cell if appropriate conditions exist. Therefore, sediment yield is calculated as the sediment generated in the cell, plus the sediment entering from cells upstream, minus the sediment deposited in the cell.

Cell erosion refers to the amount of sediment that is produced by the storm event within an individual cell rather than the cumulative amount passing through the cell. It is useful in identifying the cells that experience the greatest amount of internal erosion. The most important factors contributing to high erodibility within a given cell are soil erodibility (i.e., K-factor) and land slope. Land use, water flow velocity, and the presence/absence of defined stream channels within a cell also influence erosion. Areas of intense row-crop agriculture or unmitigated construction generally produce decidedly higher erosion losses than areas consisting of forests or wetlands. It was necessary to examine cell erosion and sediment yield in order to recognize source areas separately from conduit (i.e., "flow-through") areas. Because management options exist for both source and downstream sediment control, the distinction is often an important one. Results of the model runs are discussed below. Watershed cells with high sediment yield and high cell erosion, before and after construction, are displayed in Figures 3-9 and 3-10, respectively.

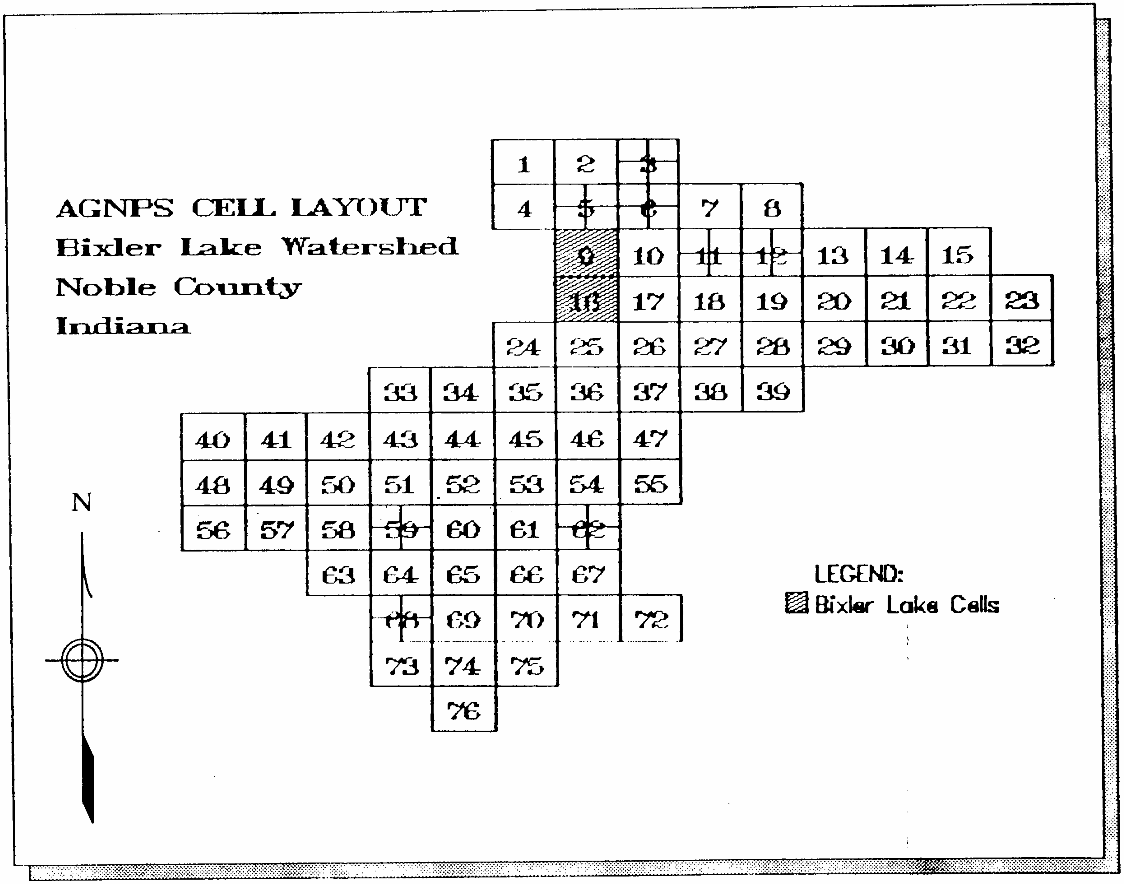

FIGURE 3-8. Layout of Bixler Lake watershed cells used in AGNPS model.

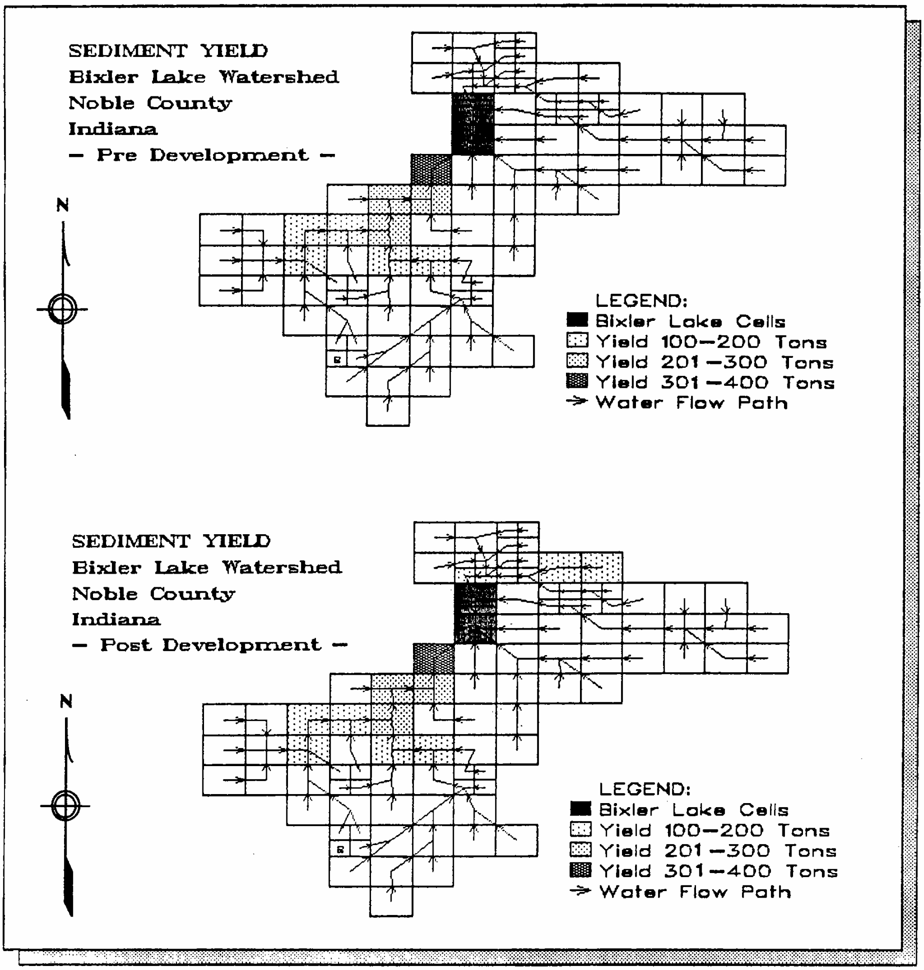

FIGURE 3-9. Sediment yield before and after construction.

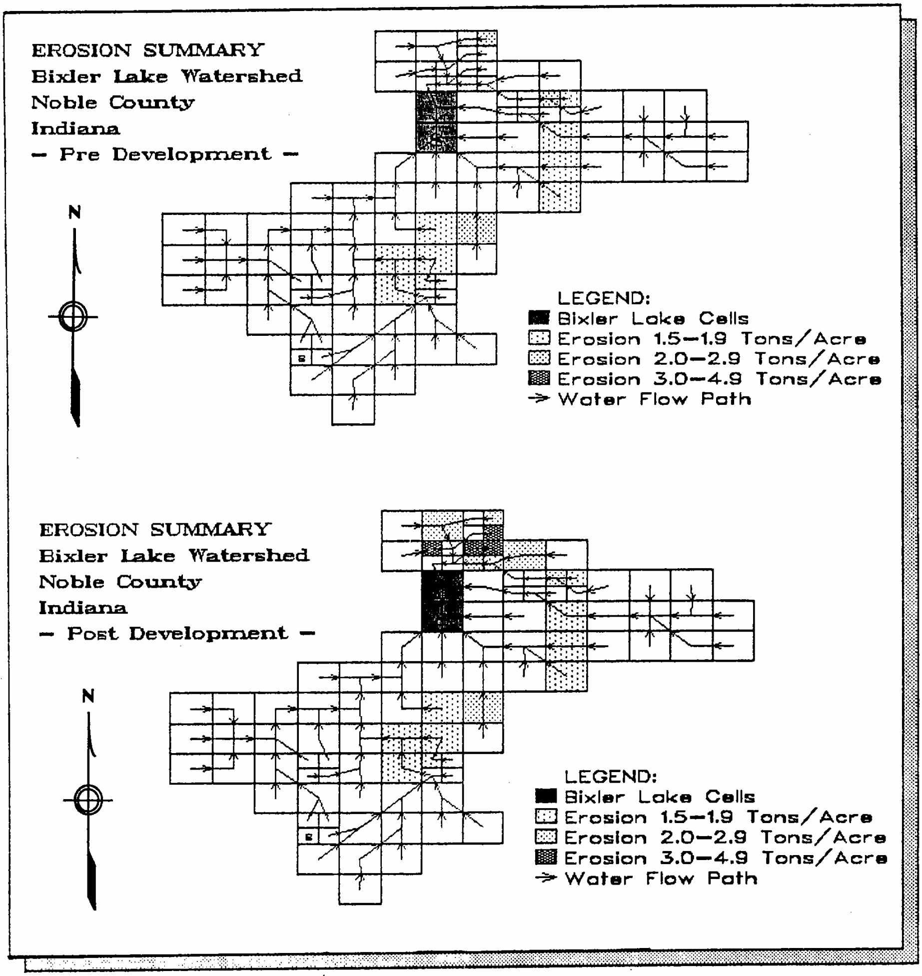

FIGURE 3-10. Modeled cell erosion before and after construction.

Before Construction: The total sediment yield into Bixler Lake prior to the land conversion was calculated at 522 tons (473 mt). The amount of sediment yield from each cell ranged from less than 1 ton (0.91 mt) to nearly 395 tons (358 mt). The cell with the highest sediment yield was cell #24. This cell represented areas adjacent to the southwestern shore of Bixler Lake and contained parts of the Kendallville City Park. While the sediment generated within cell #24 was only 0.01 tons (0.009 mt), the amount of sediment entering the cell from upstream sources was excessive. Cell #24 contained the mouth of a drainage stream that channels sediment from most of the sub-basin south of Bixler Lake. The total drainage area of this sub-basin is 1744 acres (705.8 ha), and consists of nearly half the entire catchment for the lake. The dominant land use within this area was row crop agriculture with a few isolated pockets of non-row crops. In addition, the southern-most section of this drainage area (south and east of Lisbon) was primarily comprised of highly erodible, silt-loam soils (Morley-Blount Series).

Several cells upstream from cell #24 (e.g., cells 34, 35, 44, 52, and 53) also had sediment yields in excess of 150 tons (136 mt). Collectively, they constituted the area of highest sediment load to Bixler Lake. While the relative sediment contributions of individual cells were not remarkable, the cumulative sediment drainage through this area was significant. It is important to note, however, that the location of these cells within the overall drainage scheme of Bixler Lake, rather than their physical characteristics, explains the high sediment yields predicted by AGNPS. Specifically, the modeled sediment yield from cell #24 was the result of 3 factors: (1) a large sub-basin that focused runoff at cell #24; (2) land uses conducive to high sediment export in the sub-basin; and (3) erodible soils within the sub-basin

Cell erosion figures generated by the AGNPS model for the 2-year, 24-hour storm under pre-conversion conditions ranged from no sediment production to 2.52 tons/acre (5.65 mt/ha). The average value for all cells was 0.68 tons/acre (1.52 mt/ha). Cells exhibiting little or no erosion were those areas consisting of water, wetlands, or peat/clay soils. The highest rate of erosion was found in cell #3-200 (i.e., main cell 3, sub-cell 200). The soil type in this sub-cell was classified as Miami loam and had a moderate "K" factor. The land use was row crop agriculture and the land slope was high at 7.1%. In this instance, the land slope and the land use were keys factors in determining the high sediment production. Cells #12-100 and #47 both displayed erosion production rates greater than 2.25 tons/acre (5.04 mt/ha). Both cells were under row-crop agriculture and consisted of soils with high "K" values.

After Construction: The amount of sediment predicted to reach the center of Bixler Lake (i.e., cell #16) as a result of the design storm after land use conversion was 541 tons (490 mt). The increase of 18.7 tons (16.9 mt) of sediment for the storm was attributed to the land use changes northeast of Bixler Lake. In fact, the AGNPS model calculated an increase of 76 tons to cell #9, which represented the northwestern corner of Bixler Lake, the area that received runoff from the construction site. Most of the incoming sediment was deposited within the cell and did not reach the center of the lake. Overall, however, the highest sediment yields in the post-development watershed were found in the same series of 6 cells (#24, #34, #35, #44, #52, #53) as before. Since these cells were not affected by the land conversion north of Bixler Lake, their sediment yields were identical to those in the pre-development scenario.

Cell erosion generated by the AGNPS model after land development ranged from no sediment production to 4.35 tons/acre (9.75 mt/ha). The average value for all cells was 0.90 tons/acre (2.02 mt/ha). A total of 14 cells and subcells were effected by the land use conversion. These 14 cells were converted from row-crop agriculture to construction sites. As row crops, these 14 cells experienced average sediment productions of 0.94 tons/acre (2.11 mt/ha). As construction sites, average erosion increased to 2.52 tons/acre (5.65 mt/ha). As might be expected, the highest rates of erosion in the post-development scenario were all found in the construction area. The highest rate of erosion, 4.35 tons/acre (9.75 mt/ha), was attributed to cell #8. Cells #3-400, #6-100, and #6-200 all showed sediment production rates of between 3.50 and 3.75 tons/acre (7.84 and 8.40 mt/ha, respectively). Cells #3-200 and #5-100 exhibited erosion rates of greater than 2.50 tons/acre (5.60 mt/ha). All of these cells had erosion rates higher than the maximum rate under the pre-development scenario. Construction site preparations were believed to increase erosion by removing all vegetation and the root zone of the soil. The surface was left without protection.

Nutrient Loading

The AGNPS model supplied estimates for nitrogen and phosphorus concentrations in runoff from the watershed. Values were produced both for sediment-bound and soluble forms of the nutrients. Again, the model furnished predictions for the entire watershed and for individual cells.

Nitrogen Loading: Using cumulative data generated by the AGNPS model for those cells bordering Bixler Lake, it was possible to calculate the total nitrogen (i.e., soluble N and sediment-bound N) loading to the water body during the design storm. For the pre-construction scenario, total nitrogen loading was 3.67 tons (3.33 mt). For the post-construction scenario, total nitrogen loading was 3.88 tons (3.52 mt). Therefore, as a result of the land conversion, predicted total nitrogen loading increased by 0.219 ton (0.199 mt) or 438 pounds (199 kg). Due to the increase in sediment loading in the post construction scenario, the sediment-bound component accounted for 88.4% of the increase. The soluble nitrogen component showed a modest increase of 11.6%. Watershed cells with high nitrogen loading before and after construction are displayed in Figure 3-11. Results of the model runs are discussed below.

During the pre-construction phase, soluble nitrogen generated within individual cells ranged from 0.01 pounds/acre (0.01 kg/ha) to 4.56 pounds/acre (5.11 kg/ha). The highest value was observed in cell #70, an agricultural/commercial area located in the southern portion of the watershed, east of Lisbon. Sediment-bound nitrogen generated in individual cells ranged from 0.00 pounds/acre (0.00 kg/ha) to 6.17 pounds/acre (6.92 kg/ha). The highest value was observed in cell #12-100, a cell completely under row crop agriculture, located between the Penn Central Railroad and the 650 North road, east of Bixler Lake.

During the post-construction phase, nitrogen production increased in individual cells. Soluble nitrogen figures ranged from 0.01 pounds/acre (0.01 kg/ha) to 4.56 pounds/acre (5.11 kg/ha). The high values were from cell #70 and #12-100, as before. Sediment-bound nitrogen, however, ranged from 0.00 pounds/acre (0.0 kg/ha) to 10.25 pounds/acre (11.49 kg/ha). The high value was from cell #8, a cell with over half of its area under construction and containing medium and low density residential areas.

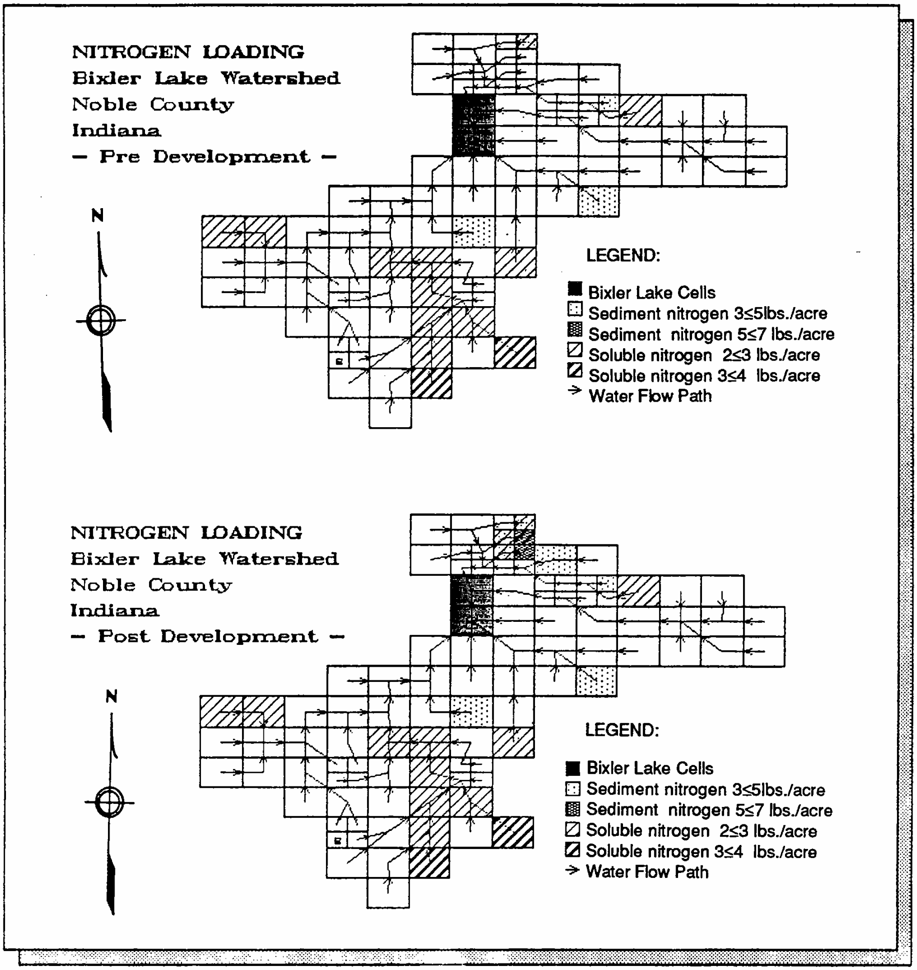

FIGURE 3-11. Modeled nitrogen loading before and after construction.

Phosphorus Loading: Total phosphorus loading to Bixler Lake was also modeled using AGNPS. Under pre-construction conditions, phosphorus loading was 1.15 tons (1.04 mt). For the post-construction simulation, total phosphorus loading was 1.25 tons (1.14 mt). Phosphorus loading after the land conversion increased by 0.103 tons (0.094 mt), or 207 pounds (94.1 kg). Of this increase, 95.6% was bound to sediment. Only 4.4% of the increase was in the soluble phosphorus component. Watershed cells with high phosphorus loading before and after construction are displayed in Figure 3-12. Results of the model runs are discussed below.

Soluble phosphorus values generated by the pre-construction conditions ranged from 0.00 pounds/acre (0.0 kg/ha) to 0.94 pounds/acre (1.05 kg/ha). The upper end of the range was found in cell #70. Sediment-bound phosphorus exhibited a range of 0.0 pounds/acre (0.0 kg/ha) to 3.09 pounds/acre (3.46 kg/ha). Cell #12-100 generated the highest value.

Soluble phosphorus values in the post-construction scenario displayed the same range as the pre-construction runs. Cell #70 produced the highest value. Sediment-bound phosphorus under the post-construction phase, however, ranged from 0.0 pounds/acre (0.0 kg/ha) to 5.13 pounds/acre (5.75 kg/ha). Cell #8 exhibited the highest value within this range.

Hydrology

The AGNPS model was also used to review hydrologic changes due to construction. Results of both modeling scenarios are presented below. Watershed cells producing high runoff volumes before and after construction are displayed in Figure 3-13.

Before Construction: For the pre-development scenario, hydrologic input to Bixler Lake was estimated to be 1.08 x 10^7 cubic feet (3.06 x 10^5 m^3). The area that contributed the greatest volume per acre was cell #14. Cell #14 produced 6500 cubic feet (184 m^3) of overland runoff per acre. Land use in cell #14, located east of Bixler Lake and north of the Penn Central Railroad, was found to be over 90% commercial/industrial. Its high runoff contribution was believed to be the result of large areas of impervious surfaces, typical of commercial/industrial properties.

After Construction: After construction AGNPS estimated hydrologic inputs to be 1.09 x 10^7 cubic feet (3.08 x 10^5 m^3), an increase of 100,000 cubic feet (1416 m^3). Cell #14, unaffected by the land conversion, remained the highest per-acre source of runoff.

3.3 IDENTIFICATION OF SOURCES OF SEDIMENT AND NUTRIENT LOADING

Based on the results of the watershed analysis, storm sampling, and visual observations, the three main sources of sediments and nutrients to Bixler Lake were identified as Tributaries 1, 3, and 4 (Figure 3-14). The suspected causal agent was different on each of these streams. For Tributary 1, the agent producing large sediment inputs was believed to be a commercial/residential development that had cleared protective vegetation and left the underlying soil susceptible to erosion. For tributary 3, elevated nutrient loads were thought to result from park land runoff and septic system leachate. For

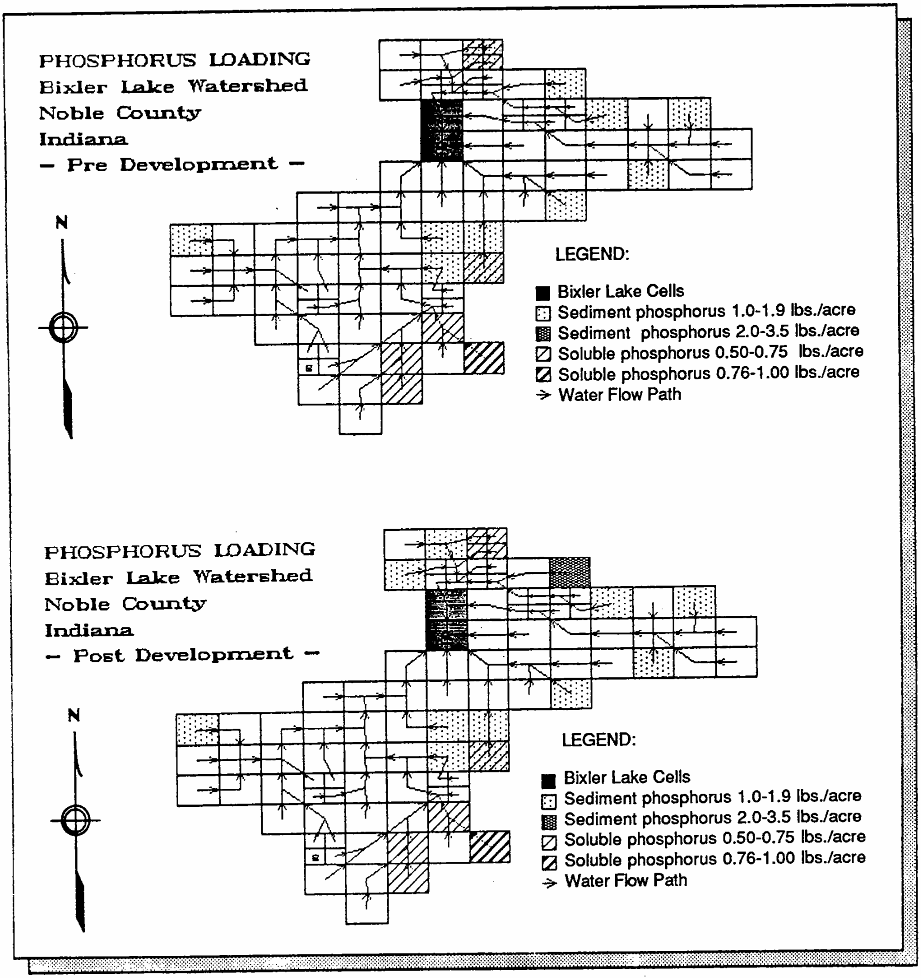

FIGURE 3-12. Modeled phosphorus loading before and after consruction.

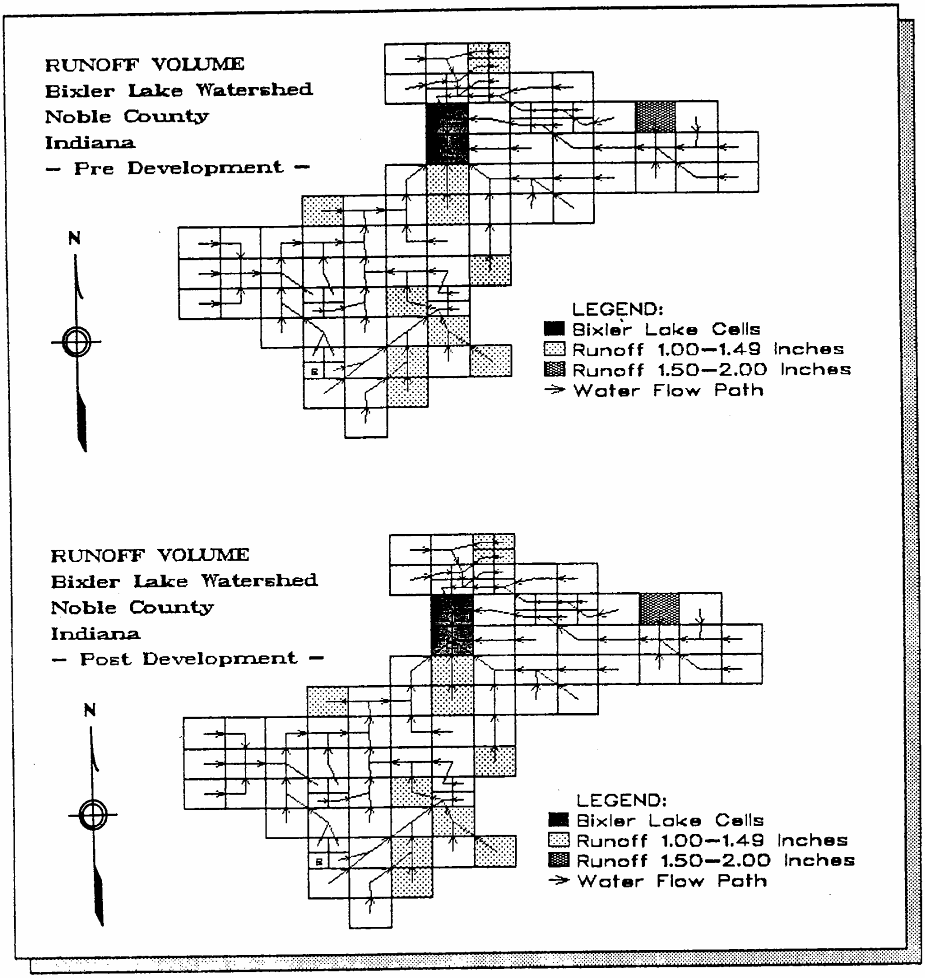

FIGURE 3-13. Modeled runoff volume before and after construction.

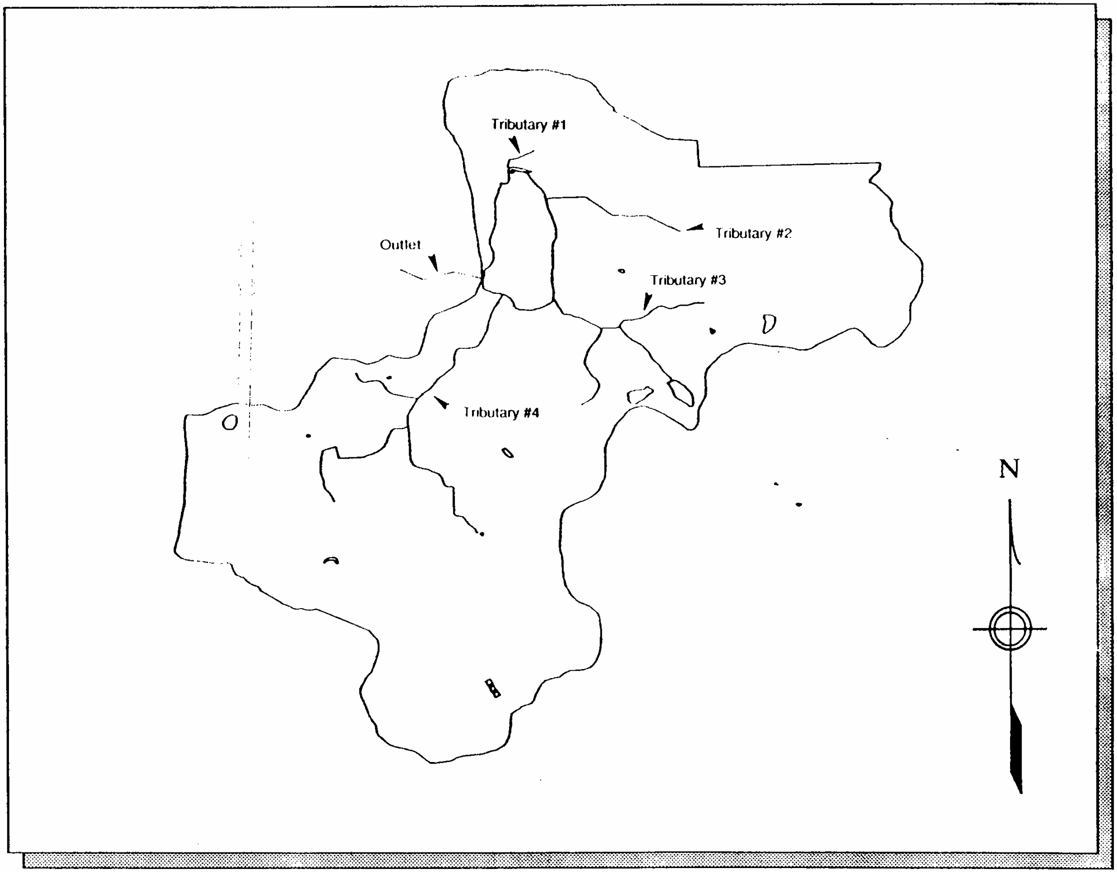

FIGURE 3-14. Location of tributaries to Bixler Lake.

PHOTO 3-1. Sediment laden water entering Bixler Lake near the ditch/canal on the northern shore.

PHOTO 3-2. Sediment laden water from the construction site entering the ditch/canal on the northern shore of Bixler Lake.

PHOTO 3-3. Flooded woodland that receives run-off directly from the construction site on the north side of the railroad tracks.

PHOTO 3-4. Culvert outlet draining the construction site.

PHOTO 3-5. Detention basin and eroded areas on the southern edge of the construction site.

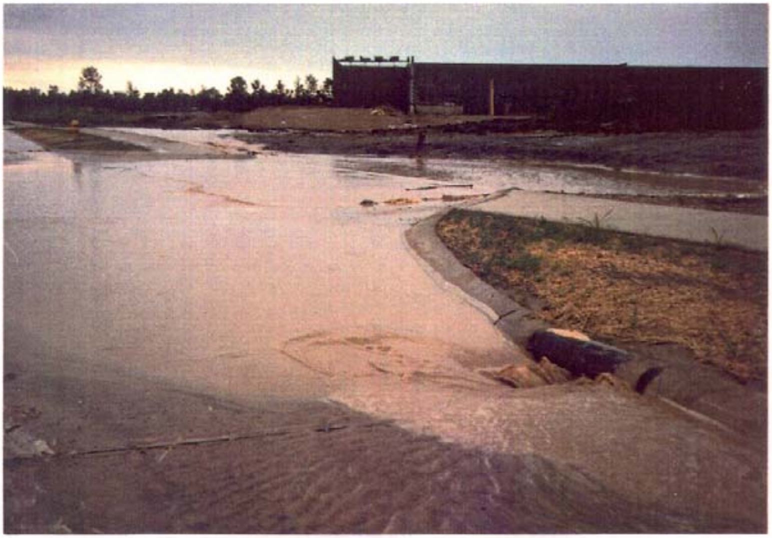

PHOTO 3-6. Sediment laden water entering storm drains on the construction site.

tributary 4, however, no single source of contamination was identified. Because the sub-basin drained by Tributary 4 comprises nearly half of the entire watershed, the cumulative impacts of many upland activities may be expected to result in high pollutant loads to the lake. It should be noted that atmospheric nutrient inputs may also be important, although more detailed monitoring must be conducted before definitive statements can be made. The following paragraphs briefly describe each source of loading to Bixler Lake.

3.3.1 Sediment Sources

IS&T field personnel inspected the tributaries to Bixler Lake immediately after a rain storm on 11 July 1989. The objective of this inspection was to identify the tributary (or tributaries) that appeared to be transporting significant amounts of suspended sediment. Written notes and photographs were taken to document all observations. The inspection revealed that the canal on the north end of the lake was flowing at a very high rate and was highly turbid with light-tan suspended sediments (Photo 3-1). The majority of the flow and sediment was being contributed by the ditch that flows into the canal from the northwest under Penn Central railroad tracks and through a corrugated metal pipe (Photo 3-2), later labeled Tributary 1. Flows in the canal upstream of the confluence with this ditch were relatively low, exhibiting much less turbidity.

IS&T staff inspected the length of the ditch to determine the ultimate source of the high flows and sediment loads. A large area of flooded woodland was observed on the north side of the railroad tracks (Photo 3-3). Storm runoff was backed up in this area by the culvert that passes under the railroad tracks. The majority of water in this flooded area appeared to be coming from a corrugated metal pipe that passes under the 650 N Road and drains a large commercial and residential development (Photo 3-4).

The area of development had been cleared more than six months before to prepare for construction and much of the cleared land had been left sparsely vegetated or bare. The soils throughout the area were fully saturated and very soft. Significant amounts of erosion and mobilized sediment were observed throughout the area (Photo 3-5). Significant amounts of sediment were observed to be entering street drains (Photo 3-6) at the site. These drains lead to the pipe at the 650 N Road.

There was evidence of efforts to control erosion and sediments in the area under construction. A rudimentary sedimentation basin had been dug on the upstream side of the 650 N Road (Photo 3-5). There was no visible outlet control structure in this basin, however. Such a structure would be required for the basin to moderate flows and trap sediment effectively. Moreover, the basin did not appear to be large enough to provide sufficient velocity reduction or detention time for significant sedimentation to occur. Limited areas within the drainage sub-basin appeared to have been seeded and/or covered with straw mulch in an effort to stabilize bare soils, but these efforts did not appear to have been effective (Photo 3-6).

Although no other streams appeared to be contributing excessive sediment loads to the lake during the site visit, the storm sampling and the watershed modeling exercise revealed that Tributary 4 was also a major source of sediment to the lake. The lack of visual confirmation during the site visit was probably due to a filtering effect exerted by the extensive wetlands and vegetation located in the area where Tributary 4 enters the lake.

The macrophyte beds at the mouth of the tributary were believed to slow flow and allow sediment to drop out before it reached open water. Another factor influencing the lack of visual confirmation is size of the sub-basin drained by Tributary 4. Because the catchment is so large, a time-tag occurs before the runoff generated in the farthest points of the watershed actually reach the lake. IS&T staff were probably investigating the construction site on Tributary 1 by the time any substantial sediment load was experienced at the mouth of Tributary 4.

As stated earlier, Tributary 4 is believed to be a significant source of sediments (and sediment-bound nutrients) due to the cumulative effects of erosion processes in its large drainage basin. Although individual sources of contaminants were not identified, it is likely that row-crop agriculture and poorly buffered construction sites (see land use map presented in Figure 3-7) were responsible for the bulk of the projected contaminant load. It is also possible that runoff from residential areas bordering the stream corridors contribute a substantial amount of pollutants to the lake.

Finally, it is important to note that the general morphology (i.e., shape, drainage density) and soil types in the Bixler Lake watershed leave the area susceptible to high peak flows during storm events. Because peak flow level is directly correlated with the energy content of moving waters, higher flows contain more energy, and, thus, increase the potential for erosion. Failure to consider these factors when planning any agricultural or development activity can lead to the creation of new sources of sediments and nutrients in the catchment.

3.3.2 Nutrient Sources

Tributary 3 was identified as the largest source of nutrients to Bixler Lake during the monitored storm event. Runoff from park land and leachate from park septic systems was suspected to be the cause of this loading. More detailed sampling is needed before quantitative statements can be made, however. Simple management procedures for controlling inputs from septic systems and runoff will be addressed in Section 4 of this report.

The construction site above Tributary 1 was also identified as a significant contributor of sediment-bound nutrients in the Bixler Lake system. From a management standpoint, controlling sediment export from the construction site would lead to improved nutrient conditions.

Sanitary sewers that will eventually convey waste water from residences and businesses in the development area above Tributary 1 also constitute a potential concern for the Bixler Lake managers. These systems should be monitored to ensure that cracks or ruptures do not develop as the system ages. Storm drainage at the site is extremely efficient and any leaking sewage would be rapidly transported to the lake. Such drainage could become a significant source of nutrient input in the future.

Loading from the atmosphere may constitute a significant source of nutrients to Bixler Lake. Because available data on climatic chemistry were not especially reliable (i.e., they were collected at distant monitoring stations) and because annual modeling of non-atmospheric inputs was beyond the scope of this feasibility study, meaningful comparisons of the relative contributions from airborne and watershed sources were not attempted. Therefore, the importance of atmospheric source in relation to other sources was not determined. It should be stated, however, that Bixler Lake is not experiencing serious impairment due to nutrient enrichment. Instead, the main problem is accelerated sedimentation. If nutrient loading and eutrophication become major concerns in the future, atmospheric sources should be investigated at that time.

SECTION 4. SEDIMENT AND NUTRIENT CONTROL TECHNOLOGIES

An overview of nutrient and sediment control technologies is presented in this section of the report. Because the most important problem facing Bixler Lake appears to be accelerated sedimentation (brought about by agricultural and developmental procedures) and because much of the nutrient load is sediment-bound, the management options most likely to bring about improvements are sediment and erosion control practices. Moreover, the tendency of the watershed toward rapid, efficient drainage exacerbates the problem of sedimentation and sediment-bound nutrient inputs (i.e., through increased erosional energy) and requires strict erosion prevention. Therefore, the majority of this section will address sediment control technologies. A discussion of septic system and park maintenance procedures is also provided.

The pollution control measures outlined in this report are directed toward specific targets identified in the catchments of Tributaries 1 and 3. General control technologies applicable to Tributary 4, where no single source was recognized, may be found in literature dealing with agricultural BMPs (e.g., conservation tillage, animal waste management, field buffer strips). Reports on these should be available through the Soil Conservation Service District Office. Some of the urban BMPs listed in this report (Section 4.2.4) will be applicable to residential areas within the Tributary 4 sub-basin.

4.1 PARK MANAGEMENT ISSUES

Although Kendallville has a sanitary sewer system that conveys waste water to a treatment plant discharging downstream of Bixler Lake, the performance of the septic system that serves the large public recreation facility in the eastern portion of Bixler Lake Park should remain a concern to managers. Storm sampling indicated significant nutrient loading from Tributary 3, which flows by the campground and sports area. Septic leachate and enriched runoff were suspected contributors to this problem. More detailed sampling and on-site investigation, beyond the scope of this study, is required before causal relationships can be established.

4.1.1 Septic Systems

To evaluate nutrient export from septic systems, it is necessary to obtain accurate information on the following parameters: (1) number of people using the system; (2) age of the system; and (3) life expectancy of the system. Unfortunately, it was not possible to adequately address nutrient export from the septic systems in the park because no information existed on rest room usage. Estimates of rest room use, based on the number of people visiting the park, were not attempted due to a lack of data on general attendance during non-weekend and non-holiday periods. Typically, if rest room usage is known (or can be reasonably estimated), per-capita nutrient contribution figures may be obtained from the literature and applied to generate an approximation of nutrient loading. Once septic system inputs are determined, calculations based on system age and life expectancy can then be used to establish the degree of nutrient "leaking" expected from the system.

If eutrophication (or groundwater pollution) becomes a major issue in the management of Bixler Lake, it is suggested that Park Department officials investigate septic loading in more detail. In the meantime, the following paragraphs offer guidance on septic system use/maintenance.

Proper Location: The drain field of a septic system should be situated in a suitable location. The features governing appropriate placement include proper soils and adequate buffer distances between the drain field and sensitive areas. Soil manuals available from the U.S. Soil Conservation Service provide maps and building suitability classes for all soil types in the area. These manuals should be consulted before installing any new system because inappropriate soils can cause system failure in less than 1 year. Minimum suggested buffer distances between the drain field and selected sensitive areas are presented in Table 4-1.

TABLE 4-1. Buffer distances between drain fields and selected sensitive areas (VWRRC, 1985).

SENSITIVE AREA	DISTANCE (feet)	(m)
Building Foundations	10.0	3.0
Drainage Ditches (above seasonal water table)	10.0	3.0
Drainage Ditches (below seasonal water table)	70.0	21.3
Natural Lakes and Impoundments	50.0	15.2
Private Drinking Water Wells	100.0	30.5
Public Drinking Water Wells	50.0	15.2
Rock and Impervious Layers	1.0	0.3
Sinkholes	100.0	30.5
Springs	200.0	61.0
Streams	50.0	15.2

Routine Inspection: A septic tank should be inspected at least once a year to assess the rate of scum and solids accumulation. If these materials are allowed to build up, they can be carried with the waste water to the drain field where they clog soil pores. Once the pores become clogged, a new drain field must be constructed. By periodically inspecting and pumping out the septic tank, this major expense can be avoided. (NOTE: inspections should be performed by trained individuals due to the flammable and toxic gases that accumulate in the tank.)

Regular Maintenance: Septic tanks should be pumped out by a reputable pumping service at regular intervals. "Tee-joints" and distribution boxes should be inspected as part of this routine maintenance since these parts are especially prone to shifting that can lead to uneven dispersal of waste water into the drain field. Material removed from the tank, known as septage, should be disposed in an approved, sanitary manner (e.g., treated and discharged at a treatment plant). Failure to have the tank pumped according to an appropriate schedule is a leading cause of septic system failure.

Drain Field Protection: Do not plant trees or allow vehicular traffic on top of the drain field. Tree roots can penetrate the drain field, diminishing its efficiency. Motor vehicles can cause significant compaction of soils in the leach field, thereby reducing the waste treatment capacity.

Proper Use: Do not dispose solids, greases, or toxic materials in septic systems. Solids (e.g., cigarette butts, paper towels, disposable diapers) add to the overall load of the system, decreasing efficiency and increasing maintenance costs. Fats, oils, and greases can solidify in the system and create blockages. Toxic materials (e.g., paints, motor oil, pesticides) are not decomposed by septic systems and can leach out into ground water and eventually reach lakes, streams, and drinking water supplies. In addition, these materials can kill the beneficial bacteria responsible for decomposing normal septic system wastes.

Additives: Authorities agree that under most circumstances, chemical and biological additives are not needed to accelerate decomposition in the septic field. Under extreme use situations, however, these additives may be helpful. Caution must be observed when using these products since some have been found to inhibit the septic action in the system. Products containing more than one percent of the following chemicals should not be used:

- **Halogenated hydrocarbons:** trichloroethane, trichloroethylene, methylene chloride, halogenated benzenes, carbon tetrachloride;
- **Aromatic hydrocarbons:** benzene, toluene, naphthalene;
- **Phenol derivatives:** trichlorophenol, pentachlorophenol, acrolein, acrylonitrile, benzidine.

A good textbook with information on septic system design and maintenance is found in Perkins (1989).

4.1.2 Grounds Maintenance

General grounds maintenance procedures can also help reduce nutrient inputs to surface water bodies. These measures center around managing grass clipping and leaf disposal, trash collection, fertilizer application, and automobile traffic. Most of the ideas presented here are "common sense" procedures that can be extended to other areas of grounds maintenance.

Grass and Leaves: Grass clippings and raked leaves should not be disposed in or near the lake or its tributaries. Instead, these items should be bagged and transported to a local landfill or to a compost area away from water flow paths. Care should be exercised when establishing compost piles because they can become a significant source of nutrients if adequate runoff protection is not afforded.

Trash Receptacles: Trash cans and dumpsters should be emptied and cleaned on a routine basis. The number of receptacles in a designated trash-can area should be sufficient to handle all trash deposited between collections. Spillage should be avoided when emptying the receptacles and any stray materials should be retrieved and discarded properly. When cleaning the receptacles, use plain water directed from a spray nozzle. Cans may be scrubbed with a brush, if necessary. Disinfectants should be used sparingly and never allowed to drain onto the ground. Disinfectant laden water should be disposed in a drain that eventually leads to a proper sewage treatment facility. The cleaning fluids and rinse water should not be disposed in a septic system.

Holes should not be drilled into the bottom of trash barrels to afford rain water drainage. Water percolating through a trash can is high in nutrient and bacterial content and should be avoided. Covered trash cans with spring-loaded, trap-door openings (or some other closed-lid device) should be used instead of open-topped oil drums. Rusty receptacles should be replaced promptly. Trash barrels should be located at some distance from the lake or tributaries and adequate vegetated buffer areas should be maintained.

Fertilizers and Chemicals: Application of fertilizers to athletic fields and other grounds should be avoided if possible. These materials are specifically designed to enhance plant growth and will do so equally well whether in the lake or on a lawn. Parks and golf courses are commonly the largest source of plant nutrients in runoff in urban and suburban areas. Other garden chemicals (e.g., herbicides, pesticides) can also be quite harmful to aquatic environments. Unfortunately, most desirable aquatic species are extremely sensitive to these compounds and exhibit acute, sub-acute, and chronic toxic responses upon contact.

If fertilization is necessary to maintain turf in high-use areas, it is recommended that appropriate soil testing be performed prior to fertilizer application in order to determine the exact nature of nutrient requirements. Add only enough fertilizer to meet these requirements because the excess will run off to the lake quite rapidly. In addition, because nutrient export to surface water bodies can be reduced significantly by following an appropriate application schedule, the Park Department should investigate optimal timing for fertilizer addition.

Automobile Traffic: Automobile traffic across vegetated areas and along the lake shore should be limited. The weight of a vehicle compacts the ground, rendering it less able to absorb rain water, more likely to produce runoff, and more susceptible to erosion. In addition, the exhaust from internal combustion engines is high in metal, hydrocarbon, and nutrient content. These "tailpipe drippings" are a leading contributor to nutrient loading in urban and suburban runoff. Drains and waterways along roads and parking lots should be situated so that runoff is not conveyed directly into the lake or its tributaries. Ideally, storm water runoff should be routed to a treatment facility (or adjacent holding pond) with adequate capacity to handle it. If this option is not feasible, storm water should be routed across large vegetated areas before being allowed to enter the lake or tributaries. Erosion prevention and runoff control measures should be observed in these cases (Section 4.2).

Education Centers: Finally, residents and visitors should be educated on issues surrounding the lake and its care. The nature center at the park provides an excellent platform for conducting such a program. Issues addressed can range from broad-based nature appreciation exhibits to storyboards explaining why fishermen should not clean their catch in or near the lake (fish entrails and other fish-cleaning byproducts can lead to bacteriological infestation, dissolved oxygen depletion, etc.). An explanation of appropriate best management practices (BMPs) is an excellent topic for presentation at an education center.

4.2 EROSION AND SEDIMENT CONTROL TECHNOLOGY

The control of erosion and sedimentation requires an understanding of the mechanisms involved. Water erosion, as is evident in the Bixler Lake watershed, is a result of the erosive effects of rain as it falls to, or runs off of the land. The result of either erosive force is the detachment and movement of soil particles. Factors that influence the type and amount of erosion that occurs under any given rainfall condition include the nature and extent of vegetative cover, the topography, the characteristics of the soil, and the local climate.

Vegetative cover plays a critical role in controlling erosion by absorbing the impact of falling rain, holding soils together, increasing the water retention capacity of soils, slowing runoff velocity, and removing water from soils between rainfalls through evapotranspiration. Soil erosion and sediment transport can be minimized through the effective management of vegetative cover to protect and stabilize soils.

The topographic characteristics (i.e., slope, shape, and size) of a drainage basin have a strong influence on the amount of runoff and rate at which it flows off of the land. Steep slopes tend to accelerate runoff rates, and promote erosion. Large watersheds produce much higher volumes and flows of runoff than do smaller basins. Thus, changes to site topography resulting from development can have a significant impact on the quantity and velocity of runoff generated by a watershed.

The characteristics of surface and subsurface soils are fundamental to the resistance of the soils to erosive forces, and the nature of the sediment that results from erosion. Soils with high sand and silt content are normally the most highly erodible. Increasing organic and clay content characteristically results in decreased erodibility. However, once soils that are high in clay content are eroded, they tend to be easily transported.

Lastly, the frequency, duration, and intensity of rainfall events in a region will have a significant impact on the amounts and velocities of runoff that occur. Frequent and intense storms carry a relatively high potential for erosion. Seasonality may be an important factor in areas where high erosion potential coincides with poor or reduced vegetative cover.

Land development increases erosion potential through the following mechanisms:

- Removal of vegetative cover.
- Exposure of highly erodible subsurface soils.
- Reduction of the capacity of surface soils to hold water due to compaction.
- Increased impervious surface in the form of pavement and buildings.
- Alteration of natural hydrologic regime through alterations in surface roughness, drainage basin size, slope, etc.

Strategies for controlling erosion and sedimentation involve either minimizing the erosion of soil particles or intercepting particles that have been mobilized. It is generally most efficient to address the problem at the source by preventing the erosion from occurring, rather than applying mitigative techniques for removing suspended soil particles from runoff.

4.2.1 Principles of Control

The following principles for design and control generally apply to the control of erosion from land development activities (VSWCC, 1980):

- Plan the development to fit the topography, soils, drainage patterns, and natural vegetation of the site.

- Minimize the extent of area exposed and the duration of exposure.

- Apply erosion control practices to minimize on-site damage.

- Apply perimeter control practices to protect the disturbed area from off-site runoff and control sedimentation damage to areas downstream of the development site.

- Minimize runoff velocities and retain runoff on-site.

- Stabilize disturbed areas as soon as possible after final grading has been completed.

- Implement an effective maintenance program to ensure that control practices are correctly implemented and maintained.

Post-development management of erosion and sedimentation in the drainage basin is important to minimize the long-term impact of urban development on receiving waters. The basic forces driving erosion and sedimentation in developed areas are similar to those at construction sites, but impacts tend to be more subtle and occur over longer periods of time. The technologies that are employed are correspondingly different from those applied at construction sites.

4.2.2 Construction Site Control Practices

Based on the inspection of the construction development north of Bixler Lake, a number of erosion and sedimentation control technologies were identified as being appropriate for application in the drainage basin. The following discussions of these practices are at a general level of detail. Engineering design details are beyond the scope of this investigation, but are available from a variety of sources. Perhaps the best source of design information specific to Indiana is the Hoosier Heartland Resource Conservation and Development Council's Urban Development and Planning Guide (HHRCDC, 1985). All costs are presented in 1989 dollars.

<u>Phased Disruption</u>: Construction activities can be scheduled in phases to minimize the extent of land disrupted at one time and duration of that disruption. In the case of Bixler Lake, the construction development area appeared to have been cleared of vegetative cover all at once, and then left in a unstable condition for a substantial length of time. This condition has contributed significantly to the erodibility of the soils on the site. Costs associated with implementing this strategy are entirely site specific.

Road Stabilization: Several practices are available to minimize erosion and sediment transport generated by traffic in construction areas. These practices include the stabilization of freshly graded road surfaces with gravel and the installation of gravel pads at the entrances to construction sites. Gravel entrances serve to reduce the amount of sediment carried off-site on the tires of construction vehicles.

Road stabilization costs are in the range of $3.75 to $7.50 per cubic yard ($5.00 to $10.00 per m^3) using crushed stone, and $11.25 to $18.00 per cubic yard ($14.75 to $23.50 per m^3) if filter fabric is used under the stone surface. Stone pads for construction entrances cost between $3.75 to $7.50 per square yard ($4.50 to $9.00 per m^2).

Sediment Barriers: Various types of barriers may be placed in the path of runoff to detain sediment and decrease flow velocities. Such barriers may be constructed of straw bales, geotextile filter fabric, or cut brush and other cleared materials. The barriers are typically placed across, or at the toe of slopes. Sediment barriers are also effective in protecting storm drain inlets. Such barriers would intercept a significant portion of the sediment that was observed to be entering the storm drains on the site.

Costs of constructing sediment barriers are typically in the range of $4.50 to $9.00 per linear foot ($15.00 to $30.00 per linear meter). Barriers protecting storm drain inlets cost between $27.00 and $108.00 per inlet, depending on the type of material used (e.g., straw bales, gravel, filter fabric, wire mesh, etc.).

Dikes and Diversions: Dikes and diversions may be constructed of earthen fill or gravel to route surface runoff around disturbed areas, minimize flow lengths through disturbed areas, and route flows to a stabilized outlet or sediment trapping structure.

Diversion structure costs depend on the nature of the fill material and the permanency of the structure. Temporary diversions may be constructed at a cost between $0.30 and $3.00 per linear foot ($1.00 and $10.00 per linear meter). More permanent dikes and diversions may cost as much as $15.00 per linear foot ($50.00 per linear meter).

Sediment Traps and Basins: Temporary or semi-permanent basins may be constructed to contain flows long enough for sediment to settle out. Temporary basins are characteristically simple, often consisting of a ponding area formed by an earthen embankment and having a gravel outlet. Semi-permanent basins have constructed outlets designed to enhance sediment removal and control flow velocities. As discussed previously, the sediment basin observed on-site adjacent to the 650 N Road appeared to be undersized and ineffective. A properly designed basin would be effective in controlling flows and intercepting sediment at this location. An alternative sediment basin location would be the flooded bottom land area just north of the railroad tracks. In either location, an outlet control structure would be required for effective operation.

Costs associated with the construction of sediment basins are primarily a function of the size of the drainage area. A basin serving up to 25 acres (10.12 ha) may be constructed at a cost between $450 and $2,400. Drainage areas up to 100 acres (40.47 ha) will require the construction of basins costing between $4,500 and $9,600.

Outlet and Channel Protection: Gravel, riprap, and concrete may be used to protect flow routes and basin outlets from scouring and erosion. Check dams and drop structures can be installed along flow routes to reduce flow velocities. Various stream bank stabilization techniques are available using vegetation or structural measures to control instream erosion. Candidate locations include the outlet of the pipe passing under the 650 N Road and the flow route upstream of the rudimentary sediment basin.

Storm water conveyance channels may be constructed at costs ranging from \$3.00 to \$7.50 per square yard (\$3.50 to \$9.00) for grass-lined channels, to \$30.00 to \$52.00 per square yard (\$36.00 to \$62.00 per m^2) for channels lined with riprap or concrete. Stream bank protection using riprap costs between \$37.00 and \$52.00 per square yard (\$44.00 to \$62.00 per m^2). Outlet protection measures cost between \$30.00 and \$67.00 per cubic yard (\$36.00 to \$87.50 per m^2), depending on the materials used.

Establishment of Grass Cover: Temporary or permanent seeding, plugging, or sodding with fast growing grasses and other plants provides a means for quickly stabilizing disturbed areas. The choice of plant type will depend on the intended permanency of the cover, and season. All areas within the construction site that are not being actively developed are prime candidates for the establishment of vegetative cover.

Costs associated with the establishment of permanent cover will depend on the type of cover, fertilizers, chemicals, and mulching required. Typical costs are in the range of \$1,000 to \$1,200 per acre (\$2,750 to \$3,000 per ha) for a low-maintenance, general purpose cover, assuming that the area has been brought to grade and the surface prepared beforehand.

Mulching: Straw and other fibrous materials may be applied to disturbed areas to reduce erosion and runoff velocities. Jute nets and mats may also be used for the same purposes. Mulch provides for retention of moisture, a stabilized surface, and insulation to promote the growth of vegetative cover. Mulch may be anchored using liquid tackifiers (e.g., asphalt) or netting to prevent it from being blown away by the wind. Mulching would be appropriate in all areas that are planted with vegetative cover.

Costs for mulch vary significantly with the type of material used. Organic mulches, such as straw and wood fiber cost between \$225 and \$270 per acre (\$550 and \$675 per ha). Nets and mats are substantially more expensive, costing between \$1,725 per acre (\$4,300 per ha) for Mulchnet over straw and \$4,200 per acre (\$10,400 per ha) for jute netting anchored with staples.

4.2.3 Erosion and Sediment Control Plan

The process of selecting and designing appropriate sediment and erosion controls to be applied at a development site is critical to the ultimate effectiveness of the effort. The actual design and implementation of controls for a particular site are beyond the scope of this investigation. The following discussion describes the first step in any control program: an erosion and sediment control plan.

Each construction site should have an erosion and sediment control plan that is developed concurrent with site construction planning. This plan should describe the potential for erosion and sedimentation problems on the construction site and the mitigative actions that will be taken to minimize them. A typical plan has both narrative sections and graphic elements, such as maps and site plans. The narrative section presents details on site conditions, scheduling strategies, and the rationale behind the selection of particular control practices. The following elements should be included in the narrative section:

- Brief description of the project
- Characterization of existing conditions
- Description of adjacent areas that may be impacted
- Summary of soil characteristics at the site
- Identification of critical areas of high potential erodibility
- Erosion and sediment control measures to be used
- Description of post-construction stabilization
- Storm water runoff concerns and impacts
- Inspection and maintenance schedules planned
- Calculations used in designing basins, waterways, and other structural controls

The site plan normally consists of graphical materials, including the following elements:

- Vicinity map showing the site location
- Existing elevation contours of the site
- Existing vegetation on the site
- Soils
- Critical erosion areas
- Existing drainage patterns
- Final contours after grading
- Limits of clearing and grading
- Locations of various erosion and sediment control practices
- Detailed drawings of structural practices to be used

The final plan will provide comprehensive documentation of the erosion and sediment control strategies to be applied in the development of the site.

4.2.4 Post-Construction Erosion Control Practices

Storm water runoff from any developed urban area will be contaminated by dust, animal waste, oil and grease, lawn fertilizers and chemicals, and a wide range of other materials that are deposited on the ground (or on buildings) and washed off by rainfall or snow melt. These contaminants may result in problems of excessive sediment accumulation, excessive nutrient enrichment, or toxicity in streams and lakes that receive the runoff. Contaminated runoff is likely to be a problem in the areas of the Bixler Lake watershed where urban and industrial development has either occurred or is planned.

Best management practices (BMPs) for the control of urban storm water may be separated into source controls and practices that reduce the delivery of pollutants to receiving waters. Several types of practices and technologies that are commonly used in managing urban runoff are listed in Table 4-2.

TABLE 4-2. Best management practices (BMPs) available for the control of urban runoff (Cooke, et al., 1986).

SOURCE CONTROLS:	POLLUTANT REDUCTION TECHNOLOGIES:
Increased infiltration	Storm water routing
Retention	Wet and dry ponds (sedimentation basins)
Erosion control	Flow equalization
Street sweeping	Physical, chemical, and biological treatment
Fertilizer/manure management	

Source Controls: Source controls will provide the first line of defense against contaminated runoff entering Bixler Lake. Because it increases infiltration capacity, sediment/nutrient retention and erosion control, permanent vegetative cover should be established as soon as possible after construction has been completed at industrial and residential sites. Moreover, vegetation should be selected to minimize fertilizer and chemical needs in the future.

On-site retention of runoff should be promoted, where possible, by appropriately designed parking areas, infiltration trenches, and dry ponds built into the design of lawn areas. On-site retention reduces downstream flows and promotes the settling of suspended pollutants in retention areas. Surface cleaning of these retention areas (e.g., parking lots) may be required to provide maximum performance.

The importance of domestic animal waste management should be brought to the attention of home-owners in the residential areas to encourage them to pick up droppings and dispose of them properly on a daily basis. Animal droppings have been identified as a major source of nutrients and bacterial contamination in urban areas.

Pollutant Reduction: The treatment of contaminated urban storm water may be accomplished by employing a variety of techniques that use physical and biological processes to remove pollutants. Wet or dry detention ponds may be constructed along storm water routes to reduce downstream flow velocities and promote settling of suspended particulate materials. Grassed waterways provide filtration and assimilation of sediments and nutrients into the grass cover. Where local conditions are suitable, artificial wetlands may be created to intercept storm water flows and provide biological uptake of suspended and dissolved nutrients. Diversion techniques may also be used to reroute contaminated runoff away from a critical waterway and to another receiving water with greater contaminant assimilative capacity.

Some combination of source controls and treatment technologies will usually provide practical means of significantly reducing runoff pollutant loading. Some typical costs for various urban storm water management practices are presented in Table 4-3.

TABLE 4-3. Typical costs of selected urban BMPs (after Schueler, 1987).

Management Practice	Size	Cost
Dry pond/Extended detention basin	50,000 cubic feet (1416.0 m^3)	$21,500
Wet pond	50,000 cubic feet (1416.0 m^3)	$23,460
Infiltration trench	3,600 cubic feet (102.0 m^3)	$5,290
Grit separators	n/a	$8,625
Grassed swales	15 by 150 feet (4.6 by 45.7 m)	$860
Wetland planting	5 acres (2.02 ha)	$11,500

4.3 EROSION CONTROL PROGRAM

An effective program for the protection of Bixler Lake and similar waters from the impacts of excessive erosion will require a mechanism for encouraging developers and landowners to implement mitigation measures during and after construction. The most successful program will probably include both voluntary efforts and mandated requirements defined through environmental regulations.

Educational programs may be effective in increasing awareness in the development and construction community about the threats that urban development poses to lakes and streams in the region. Individual landowners may also be receptive to public education regarding the control of erosion during land clearing and construction. Technical materials are available from a variety of sources, including the Hoosier Heartland Resource Conservation and Development Council, the Soil Conservation Service, state agencies, and regional authorities. Several sources of technical information on the planning, design, and implementation of erosion control programs are listed in Table 4-4.

The implementation of erosion controls requires significant expenditures in time and resources. As a result, it is reasonable to expect that a successful control program will require a regulatory structure to ensure compliance to specific technical requirements. It is beyond the scope of this investigation to discuss the legal issues surrounding erosion control legislation at the local level, but this is a topic that should be addressed by the Town of Kendallville and Noble County.

TABLE 4-4. Sources of technical information on erosion and sediment control technologies for urban watersheds.

Reference Texts:

Handbook of Nonpoint Pollution
Novotny, V. and G. Chesters, Van Nostrand Reinhold. 1981.

Urban Stormwater Management and Technology: Update and Users' Guide.
Lager, J., W. Smith, W. Lynard, R. Finn, and E. Finnmore. U.S. Environmental Protection Agency, Cincinnati, OH 45268. EPA-600/8-77-014. 1977.

Design Manuals:

Urban Development and Planning Guide.
The Hoosier Heartland Resource Conservation and Development Council, 5995 Lakeside Blvd., Suite B, Indianapolis, IN 46278. 1985.

Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs.
Schueler, T., Metropolitan Washington Council of Governments. 777 N. Capitol St., Suite 300, Washington, DC 20002. 1987.

Maryland Standards and Specifications for Infiltration Practices.
Maryland Department of Natural Resources, Water Resources Administration, Tawes State Office Building, Annapolis, MD 21401. 1984.

Virginia Sediment and Erosion Control Handbook.
Virginia Department of Conservation and Historic Resources, Division of Soil and Water Conservation, 203 Governor St., Suite 206, Richmond, VA 23219. 1980.

Best Management Practices Handbook - Urban.
Planning Bulletin No. 321. Virginia State Water Control Board. 1979.

SECTION 5. LONG-TERM MONITORING PROGRAM

A long-term water quality and sediment monitoring program is required for Bixler Lake to provide a basis for detecting changes in lake quality. The objective should be to collect appropriate information to assess the general condition of the lake and draw basic conclusions regarding future changes that may be observed. Moreover, if a decline in quality is observed, and the causes are not evident to local resource managers, the data collected under this program will provide the level of detail required for a professional lake manager to analyze the situation. This section describes the basic components of a monitoring program that could be conducted by the Kendallville Park and Recreation Department, with some assistance from a local analytical laboratory. The program is described in two parts: data collection and data interpretation.

5.1 DATA COLLECTION

The core of the monitoring program will be the routine collection of water quality and sediment depth measurements. Consideration should also be given to the collection of storm flow samples from the tributaries to the lake to monitor the quality of storm runoff.

5.1.1 Lake Water Quality

Water quality monitoring should include both in-situ measurements and laboratory analyses of water samples. In-lake measurements and samples should be collected at a single station at the deepest location in the lake. It is recommended that these measurements be collected on a regular monthly basis, such as the first Monday of each month. Moreover, all measurements should be taken at approximately the same time of day each month (i.e., early afternoon). In-situ measurements should include Secchi disk transparency and temperature and dissolved oxygen profiles (e.g., measurements taken at two-foot intervals from the surface to the bottom). The instrumentation required for these measurements may be purchased for between $850 and $1,000.

Water quality samples should be collected at the surface, at mid-depth, and approximately one foot above the bottom of the lake. Samples should be analyzed for total phosphorus, total nitrogen, and chlorophyll a. A suitable Van Dorn-type water sampler may be purchased for approximately $400. Analytical costs will be entirely dependent on the laboratory used. To minimize costs it is recommended that a local waste water treatment plant or health department laboratory be utilized, if at all possible.

5.1.2 Tributary Storm Samples

Because sediment loading is the principal issue of concern in Bixler Lake, a basic program of tributary storm sampling is recommended. In sampling storm runoff there is a compromise between the ideal, which would involve flow-weighted samples collected throughout each storm hydrograph, and the practical constraints of limited funds to support the program. Flow-weighted sampling is very expensive, requiring sophisticated automatic monitoring and control packages, auto-samplers, establishment of accurate hydraulic control sections and corresponding rating curves, and substantial labor to maintain the equipment. In contrast, grab samples may be collected manually and only require some sort of sampling container, typically a bottle or jar. The disadvantage of grab samples is that they only represent a single moment in the storm hydrograph and pollutant concentrations are known to vary significantly throughout the duration of a storm. However, the consistent collection of many grab samples over a period of time can provide a basis for comparison among tributaries and detection of large changes in loading through time.

It is recommended that grab samples be collected during storm flows at the four tributaries that discharge into the lake. The ideal timing for collection of these samples will be at, or just before the peak flow in each tributary. Storm samples should be analyzed for total suspended solids. Optionally, and if funding is available, these samples may also be analyzed for total phosphorus and total nitrogen.

5.1.3 Sediment Accumulation

The results of this study indicate that Bixler Lake is accumulating sediment, especially in the northernmost part of the lake adjacent to the mouth of the canal. The southernmost shoreline may also be suffering sediment accumulation from material discharged from the two tributaries on the southern shore. Water depths in these two areas of the lake should be measured at least on an annual basis to monitor sediment accumulation.

Sediment monitoring stations should be established on transects along the centerline of each of the three tributaries and extending out into the lake several hundred feet. The stations should be spaced at approximately 100 ft. intervals along each transect. Stations should be located using surveyor's instruments, such as an electronic distance measuring device (EDM), to allow the depth measurements to be taken at the same location each time. At each station, depth to the surface of the sediment should be measured using a surveyor's rod, or similar calibrated pole. Lake surface elevation should be recorded for each round of station measurements to ensure that all measurements are referenced to a common horizontal datum.

5.2 DATA MANAGEMENT

A single individual should be responsible for all data collection and records maintenance to ensure that the monitoring is conducted reliably and consistently. Consistency of technique and analytical methods is essential to minimize random variability in the data and maximize the value of the collected information in detecting changes over time.

Standardized data forms should be developed and used for all field measurements, sample collection, and reporting of laboratory results. The forms should be simple, but complete, and as easy to use in the field as possible. For enhanced retrieval, reporting, and analysis, the collected data should be entered into a microcomputer-based database. There are numerous software packages on the market that provide the necessary features for ease of maintenance, statistical analyses, and graphics.

5.3 DATA INTERPRETATION

The monthly data generated by this program will provide a general characterization of Bixler Lake. Detailed interpretation of this type of time-series data must account for, and isolate, seasonal effects and natural variability; analyses that are best left to technical specialists with specific training and experience. However, there are some simple methods for presenting the data that will allow local lake managers to utilize the data and draw some basic conclusions.

Graphic plots of the water quality and sediment data should be maintained as a basic interpretive tool. An example of a water quality time-series data plot is presented in Figure 5-1. Similar plots can be used to detect seasonal trends, long-term trends, and differences in extreme values between years. Often, fitting of a simple linear regression through time-series data will allow the detection of a long-term increase or decrease in a measured parameter (i.e., Secchi disk transparency or depth to sediment). Such a trend would be revealed by a regression slope that is significantly different from zero.

Water quality parameters may be evaluated in terms of annual statistics. A simple example would be the examination of the average annual Secchi disk transparency along with the range of transparencies observed during the year. A trend of decreasing annual means and minimum transparencies would suggest that either suspended sediment or algae concentrations are increasing. A good limnological text, such as Wetzel (1983) or Reid (1961), will provide more detailed interpretive guidance than can be provided within the scope of this investigation.

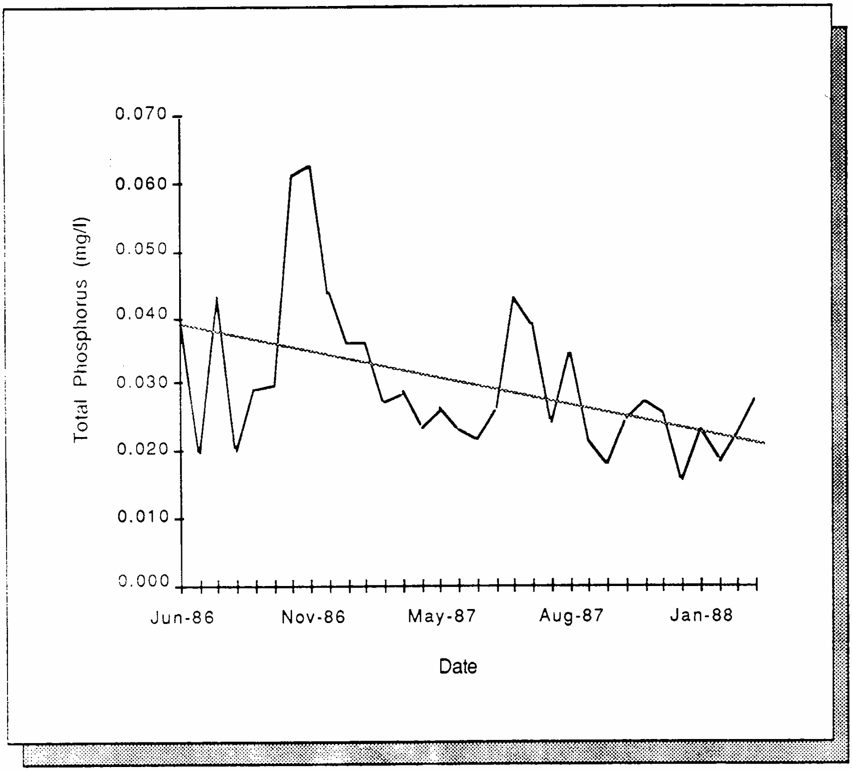

FIGURE 5-1. Example of a time series plot of lake phosphorus concentrations with a regression line fitted. The data indicates a trend of declining concentrations.

SECTION 6. RECOMMENDATIONS

The results of this study indicate that Bixler Lake is a small- to medium-sized water body experiencing moderate sedimentation and eutrophication problems. The extent of these impairments, however, is generally not severe enough to warrant large-scale restoration measures. Simple techniques such as limited macrophyte harvesting, chemical controls (e.g., herbicides), and nutrient deactivation may be appropriate for improving conditions in the lake itself. The primary thrust of management efforts should be directed at short- and long-term control of sediment and nutrient production off-site. Limiting the input of these parameters offers the most promising avenue for maintaining the quality of the lake resource. A general, integrated program for managing Bixler Lake should include: (1) reviewing waste water treatment and park runoff management plans; (2) applying upland best management practices (BMPs); and (3) performing modest in-lake restoration. A brief outline of these management activities is presented below (emphasis should be placed on the first two):

1. Review waste water treatment and park runoff management plans:

    a. Ensure adequate septic system capacity for peak use periods and implement appropriate maintenance routines (e.g., periodic pump-out in the short term and relocation\reinstallation in the long term).

    b. Install any new septic systems in appropriate soil-types, with adequate distance buffers between leach fields and lake/tributary systems.

    c. Evaluate grounds maintenance operations (e.g., fertilizer application rate/timing; grass/leaf disposal; trash and trash receptacle management); and establish procedures that minimize overland runoff and transport of nutrients and sediments.

2. Apply best management practices:

    a. Encourage the use of agricultural BMPs (e.g., low-impact tillage, field buffer strips, animal waste management) in coordination with representatives from the U.S. Agricultural Stabilization and Conservation Service (ASCS) and the U.S. Soil Conservation Service (SCS).

    b. Protect wetland areas (especially along tributaries) that act as sediment/nutrient filters for incoming pollutants.

    c. Implement effective erosion control measures at construction sites and in residential areas.

    d. Develop, enact, and enforce appropriate zoning and development planning regulations for controlling the production of off-site pollutants.

3. Perform in-lake restoration as needed only:

   a. Harvest only those macrophytes that are causing significant navigational problems; do not attempt to eradicate aquatic plants because they perform much needed filtering, especially at tributary entrances.

   b. If following management recommendations outlined by IDEM (1986) use physical/chemical treatment methods sparingly. These methods should be targeted at changing nutrient availability to aquatic plants; removing the nutrients from the photic zone; or preventing the release/recycle of nutrients from the sediments.

   c. Conduct a fishery study during the early 1990s to monitor carp population growth and take appropriate control measures to ensure maintenance of vegetative integrity and water quality.

In addition to these recommendations, it is believed that a sustained program of seasonal monitoring will enable managers to identify and evaluate trends in Bixler Lake and address their implications in a timely and efficient manner.

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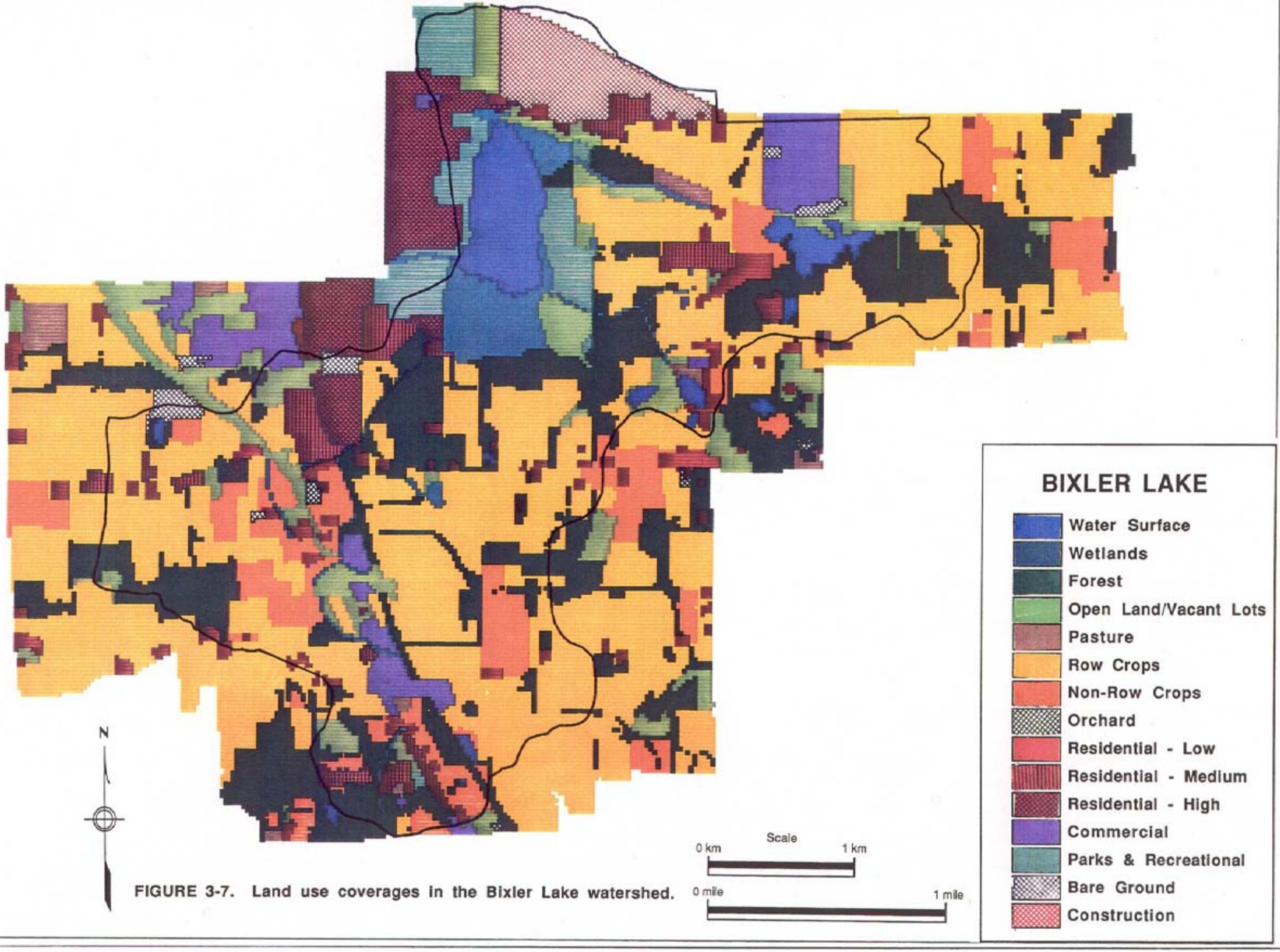

FIGURE 3-7. Land use coverages in the Bixler Lake watershed.

PHOTO 3-1. Sediment laden water entering Bixler Lake near the ditch/canal on the northern shore.

PHOTO 3-2. Sediment laden water from the construction site entering the ditch/canal on the northern shore of Bixler Lake.

PHOTO 3-3. Flooded woodland that receives run-off directly from the construction site on the north side of the railroad tracks.

PHOTO 3-4. Culvert outlet draining the construction site.

PHOTO 3-5. Detention basin and eroded areas on the southern edge of the construction site.

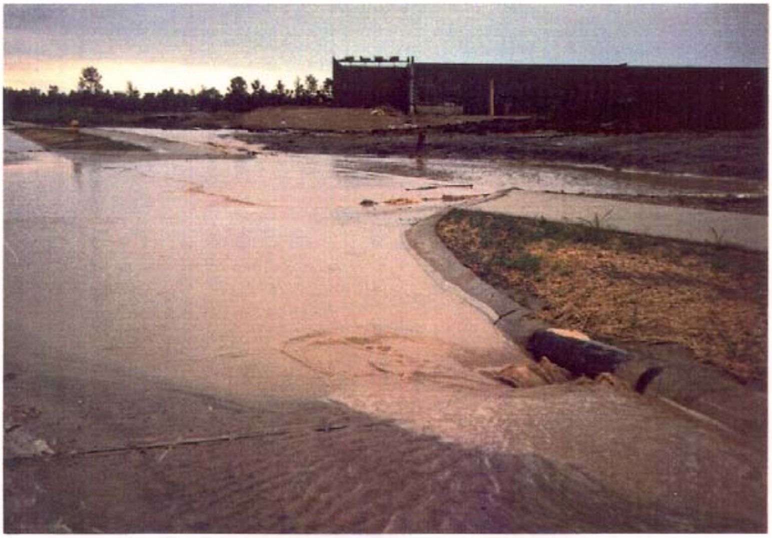

PHOTO 3-6. Sediment laden water entering storm drains on the construction site.